Studies on factors affecting the infiltration capacity of agricultural soils

Von der
Fakultät Architektur, Bauingenieurwesen und Umweltwissenschaften
der Technischen Universität Carolo-Wilhelmina
zu Braunschweig

zur Erlangung des Grades eines
Doktors der Naturwissenschaften (Dr. rer. nat.)
genehmigte

Dissertation

von

Rajeh Alhassoun
geboren am 01.01.1976
aus Homs, Syrien

Eingereicht am 07. Mai 2009

Disputation am 02. Juli 2009

Berichterstatter Prof. Dr. Matthias Schöniger

Prof. Dr. Dr. Ewald Schnug

(2009)

Acknowledgements

I would like to express my deepest gratitude with special thanks to Prof. Dr. Ewald Schnug for his guidance and encouragement. Similarly, I am so grateful and thankful to Prof. Dr Matthias Schöniger, Prof. Dr. Wolfgang Durner, and Prof. Dr. Klaus Fricke for their cooperation and guidance. I am also very grateful and thankful to Prof. Dr. Jutta Rogasik for her great efforts and kind encouragement. My special thanks also to Dr. Holger Lilienthal, Dr. Kirsten Stöven and Ute Funder for help and cooperation. Finally, I would thank all colleagues and everybody who contributed in this work.

Abstract

Water flooding induced by heavy rainfalls or river floods can harm agricultural soils. In particular, it leads to soil erosion and thus soil losses by high rates of surface runoff. Therefore, mitigation of the negative effects of flooding on soils is strongly needed. In this context, the soil infiltration capacity was considered as an important parameter in decreasing the surface runoff by increasing the water infiltration into the soil, and thus enhancing the soil protection against water erosion.

The main aim of the present work was to identify the most important factors affecting the infiltration capacity of agricultural soils as a fundamental method for soil protection against early flooding.

The effects of different land use and farming management systems on the water infiltration rates of soils were investigated at three experimental sites, in Braunschweig, Trenthorst and Mariensee. The results of the study revealed that the infiltration rate was strongly influenced by the land use systems. The highest infiltration rate was in the forest followed by grassland and the lowest was measured in arable land. In addition, it was found that the soil infiltration rate was considerably affected by the agricultural management practices. Organic farming resulted in a better soil structure and supported higher earthworm populations resulting in high numbers of biopores, which significantly contributed to increased water infiltration rates. Conservation and reduced tillage systems resulted in a high soil aggregate stability and produced larger numbers of earthworms, in particular the deep dwelling worms” anecic”, resulting in higher numbers of macropores with high continuity and connectivity which have an important role for the enhancement of water infiltration rates into the soil profile. Organic fertilization resulted in improved soil properties, which in turn positively affected the infiltration rate. Besides, the study revealed that the high infiltration rates were a consequence of improved soil properties, which can provide a high protection for soils against degradation or erosion. Therefore, the infiltration rate can reflect the level of soil protection. Thus, the study deduced that the infiltration rate could be used as an indicator of soil protection.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1 Introduction

1.1 Background

Water is the essential constituent of all life on earth. In spite of the fact that water is a vital source of life, it is simultaneously considered as a source of death and destruction, induced mainly by river floods related to heavy precipitation. These floods are looked at as a real threat to humankind since old ages and are still so at the present time (Sparovek et al, 2002). Substantially, flooding involves many risks and causes significant damage to the areas in which it takes place. Infrastructure situated close to rivers can be destroyed. In addition, floods induce great soil erosion resulting in significant losses in soils as well as the deterioration in soil quality. This adversely affects agricultural production. Moreover, floods generated by heavy rainfall water can produce surface runoff, which causes pollution of surface water with conveyed chemicals, fertilizers and pesticides, (Holland, 2004).

Soil sealing and the expansion of urban areas are considered as main causes for river floods. For example, in Germany about 120 ha of agricultural lands are lost every day for urbanization (Statistisches Bundesamt, 2008). The complex reasons that result in river floods are not yet fully understood and flood prediction is still far from being accurate. The water from precipitation that ends up in the rivers by runoff is considered a basic cause related to floods. Hence, losses in the water infiltration capacity of soils tend to be the reason for frequent floods (Sparovek et al., 2002). Consequently, enhancing water infiltration potential into the soils becomes a very important task to diminish surface runoff during heavy storms and to avoid, or mitigate, the adverse impacts of river floods.

Infiltration is the entry of water into the soil. The rate of infiltration determines the amount of water, which will enter the soil and the amount of water, which will run on soil surface as runoff (Hillel, 1982). Therefore, the water infiltration rate can be considered as an important soil property which significantly influences the amount of surface runoff and hence, the degree of soil erosion. Basic steady state infiltration rates for different soil types are summarized in Table 1.1.

Tab. 1.1: Steady state infiltration rates for different types of soil (Shukla and Lal, 2006).

Soil type	Steady infiltration rate (mm h^{-1})
Sand	>30
Sandy loam	20-30
Loam	10-20
Clay loam	5-10
Clay	1-5

Since most areas of land are used for agricultural production, a small loss in the infiltration capacity of agricultural soils may produce serious impacts on flood intensity. For instance, water infiltration rates less than 15 mm/h were found to be related to increased flood intensity (Sparovek et al., 2002). Therefore, sustaining enhanced water infiltration ability into the soil of agricultural areas is considered as a precautionary way for protection against river floods. It can be concluded that water infiltration is actually one of the preservative means of soils, especially against erosion induced by surface runoff.

In addition to the role of infiltration in conservation of soil against erosion, infiltration has many beneficial functions. Infiltration provides water needed for vegetation growth and it enhances the ground water storage. Moreover, infiltration is taken into account as a major element of the hydrologic cycle.

Soil erosion is a serious problem due to its environmental hazards, including on-site and off-site impacts. On-site erosion effects comprise mainly the degradation of soil structure and decrease of soil fertility, while off-site influences involve floods and pollution of the ground and surface water with nitrates and heavy metals conveyed by water runoff to the lakes, rivers and nearby fields (Lal, 1990). The rate of infiltration is affected by different chemical, biological and physical soil properties, like organic matter content, biological activity, earthworms, soil sealing and crusting, and compaction. Agricultural management practices like tillage, fertilization and crop rotation also affect the infiltration of water into the soil (Rogasik et al., 2004).

The infiltration capacity of soil is a very important factor for improving soil properties and maintenance against hazards. In this context, the study of factors affecting infiltration capacity of agricultural soils has specific importance, especially as it is associated with different agricultural practices. Supporting high infiltration capacity of soil is considered as a very important task of agriculture (Rogasik et al., 2004). On the other hand, agricultural practices can indirectly affect infiltration through their effect on earthworms. Earthworms have positive roles in the soil and affect the soil structure and water infiltration through their feeding and burrowing activities (Kladivko et al., 1986).

Earthworms contribute to the formation of stable aggregates, thus they enhance soil structure (Edwards and Bohlen, 1996). Moreover, the burrowing of earthworms produces channels and increases macropores that facilitate water flow, improving water infiltration into the soil (Zachmann and Linden, 1989). Therefore, it is necessary to study how agricultural management practices affect earthworm populations in order to adopt an adequate management that encourages higher earthworm activity and thus increased infiltration rates into the soils. Agricultural management practices comprise land use, soil tillage practices, fertilization and crop rotation. Land use and agronomic practices are very important, as they significantly influence water infiltration into soil. Infiltration rate and soil organic matter are essentially influenced by the predominant land use system (Rogasik et al., 2004; Hartge, 1988).

Numerous studies revealed that land use and management practices are the essential factors affecting soil structure and infiltration characteristics as shown in Table 1.2.

Water infiltration is strongly dependent on soil structure, and thus the limitation of water infiltration is substantially related to poor structure of soil (Conolly, 1998). This may lead to the conclusion that soils with good structure can be characterized by elevated water infiltration rates and decreased runoff, flooding and erosion potential.

Organic farming produces sustainable soil structure and high biological activity and enhances water infiltration rates and soil water holding capacity (Poudel et al., 2001). Moreover, organic farming has an important role in counteracting anthropogenic soil sealing which can lead to increased floods as a result of diminished infiltration. Furthermore, soils under organic farming will support the biological activity and have plenty of bio-pores, which in turn enhance water infiltration rates into the soil (Schnug and Haneklaus, 2002). Consequently, organic farming can be adopted as a beneficial agronomic measure for improving soil properties and enhancing soil infiltration capacity.

Tab. 1.2: Compilation of management options influencing soil properties to achieve high infiltration rates and low runoff (+ positive impact, - negative impact, = no substantial impact, in brackets weakly pronounced)

Management options	**Fundamental soil properties**						
	soil organic matter	earthworm abundance	biopores, connectivity	soil structure	land cover	**runoff**	**infiltration**
Land use							
forest	+	-	(+)	(+)	+	low	moderate
grassland	+	+	+	+	+	low	high
conventional agriculture	+/-	-	-	+/-	+/-	medium/ high	medium/ low
organic agriculture	+	+	+	+	+	low	very high
fallow	=	(-)	(-)	-/ (+)	-	high	low
Fertilization							
mineral	-	-	-	-	=	high	low
organic/ green manure	+	+	+	+	+	low	very high
Crop rotation							
favourable	+	+	+	+	+	low	high
unfavourable	-	-	-	-	-	high	low
Soil tillage							
conventional	-	-	-	-	-	high	low
Conservation/ mulching	(+)	+	+	+	+	low	high

Reference sources: Schnug and Haneklaus (2002), Rogasik et al (2004), Schmidt et al (2003), Edwards and Bohlen (1996), Hubbard et al (1999), Buczko et al (2003), Chan (2001)

The land use (forest, grassland, arable land) and the farming system (i.e. conventional and organic) have different impacts on the infiltration capacity and water storage in the soils. The knowledge about these relationships is very important to prevent or minimize soil water erosion and to guarantee high infiltration rates that will be beneficial under different climatic conditions. In the case of humid areas that have excessive rainfalls, increased soil infiltration capacity results in the storage of a great proportion of precipitation, reducing overland flows and flooding occurrence. Whereas, in the arid areas where the rainfall is limited, high soil infiltration capacity keeps most of rainwater inside the soil preventing water loss by surface runoff and evaporation.

In recent years, agronomic research has well focused on the investigation of measures maintaining or improving water infiltration as an important soil property.

Until now, soil conservation researches were aiming at erosion control. However, soil protection also needs more knowledge about the impacts of land use on other indicators, such as water infiltration into the soil profile. Therefore, more concentration is required on the strong relationship between the land use and soil properties and their influences on water infiltration into soil.

The presented study is a contribution to the investigations on factors affecting the water infiltration capacity of agricultural soils.

1.2 Infiltration theory

Infiltration is defined as the entry of water into the soil (Hillel, 1980). Infiltration rate is the velocity of water entering into the soil. It is generally estimated as mm of water that infiltrates the soil in 1 hour. There are two different terms, which express the infiltration rate, (i) the initial infiltration rate, which indicates the fast entry of water into dry soil and (ii) the equilibrium infiltration rate, which expresses the steady state infiltration rate (Rogasik et al., 2004). At first, water commences to penetrate the soil swiftly at an increasing rate but, as time passes, the infiltration rate comes near to a steady state, which nearly equals the saturated hydraulic conductivity of soil (K_S). The initial infiltration rate will be high when water is applied to dry soil (Shukla and Lal, 2006). Commonly, the infiltration rate tends to be high in the first time when the soil is completely dry, and afterwards it declines gradually to attain approximately a steady state (Shainberg and Levy, 1995).

The infiltration rate is basically affected by the capillary force, especially in the early stages of infiltration, and the gravity force. Soil type and dryness causes a difference between the initial infiltration rate and the final infiltration rate (Durner, 2008).

The measurement of the hydraulic conductivity function of soil is a difficult task (Durner, 1994). Thus, the hydraulic conductivity function of soil can be estimated depending on the water retention characteristics of soil (Durner and Lipsius, 2005). Therefore, infiltration measurement tends to be a useful way to determine the saturated hydraulic conductivity of soil. This is because, as already mentioned, the steady state infiltration rate approximately equals the saturated hydraulic conductivity of soil.

Infiltration rate varies with time depending on texture, structure, initial water content and homogeneity of the soil profile (Hillel, 1980).

There are several equations, which demonstrate the infiltration rate as a function of time or total volume of water entering the soil. The Horton-type equation explains the infiltration process as a function of cumulative rain rather than cumulative time:

$I_t = I_c + (I_i - I_c)\, e^{-ypt}$

Where:

I_t = immediate infiltration rate (mm h^{-1})

I_c = asymptotical final infiltration rate (mm h^{-1})

I_i = initial infiltration rate (mm h^{-1})

Y = constant related to aggregates stability of soil surface (mm^{-1})

P = rain intensity (mm h^{-1})

t = time passed from commencement of rainfall event (h)

Infiltration rates, which are computed on the basis of this equation, were in consistence with infiltration rates measured with rainfall simulators (Shainberg and Levy, 1995).

1.3 Objectives of the work

Water infiltration rate is considered as a vital soil property that can significantly affect the environment. Agronomic measures such as tillage practices, fertilizers treatment, crop rotation, and field traffic influence water infiltration rate into the soil. The present research work focused on the following objectives:

1. To assess the impact of different land use systems on water infiltration into the soil.
2. To investigate the influence of agricultural measures on infiltration rates in long term field experiments and off-farm trials.
3. To deduce algorithms to calculate infiltration rates for different land use and agronomic management systems
4. To develop scenarios to keep the infiltration capacity of soils as high as possible using all means of agricultural measures.

2 Material and methods

2.1 Experimental sites

Soil infiltration rate is basically dependent on the variation of soil properties which is generally controlled by the geological and pedological processes (soil type) and affected by soil and crop management practices. Land use and agronomic measures are the main criteria for the selection of the study sites. The investigations were conducted in three study sites that differ in climate, soil type, topography, and agricultural management practices. A general description of the study sites is summarized in Table 2.1.

Tab. 2.1: General description of the study sites

Location	Fields	Soil type	Land-use
Braunschweig (Südfeld / JKI-PB)	Field No. 36 Field No. 4 Field No. 10 Field No. 7 Forest	Dystric Cambisol Orthic Luvisol	Pasture, Forest, Arable land
Mariensee	Field No. 1 “ Schlag1” Field No. 2 “Vietingskamp” Field No. 3 “Kuhweide” Field No. 4 “Moorkamp” Field No. 5 “Gr.Fuchsberg”	Fluvisol, Luvisol	Arable land, Grassland
Trenthorst (Institute of Organic Farming)	Field No. 51 (Field C1) Field No. 29 (Field O1) Field No. 11 (Field O2) Field No. 8 (Field O3)	Luvisol	Arable land, Grassland

C = conventional farming system, O = organic farming system, “Kuhweide” = grassland

2.1.1 Braunschweig

Location and climate

Braunschweig (E 10^0 27`, N 52^0 18) is situated in the northeast of Germany (Fig. 2.1). The investigations were carried out in different long-term experiments in the Institute of Crop and Soil Science, which is related to Julius Kuehn Institute (JKI) (Fig. 2.2).

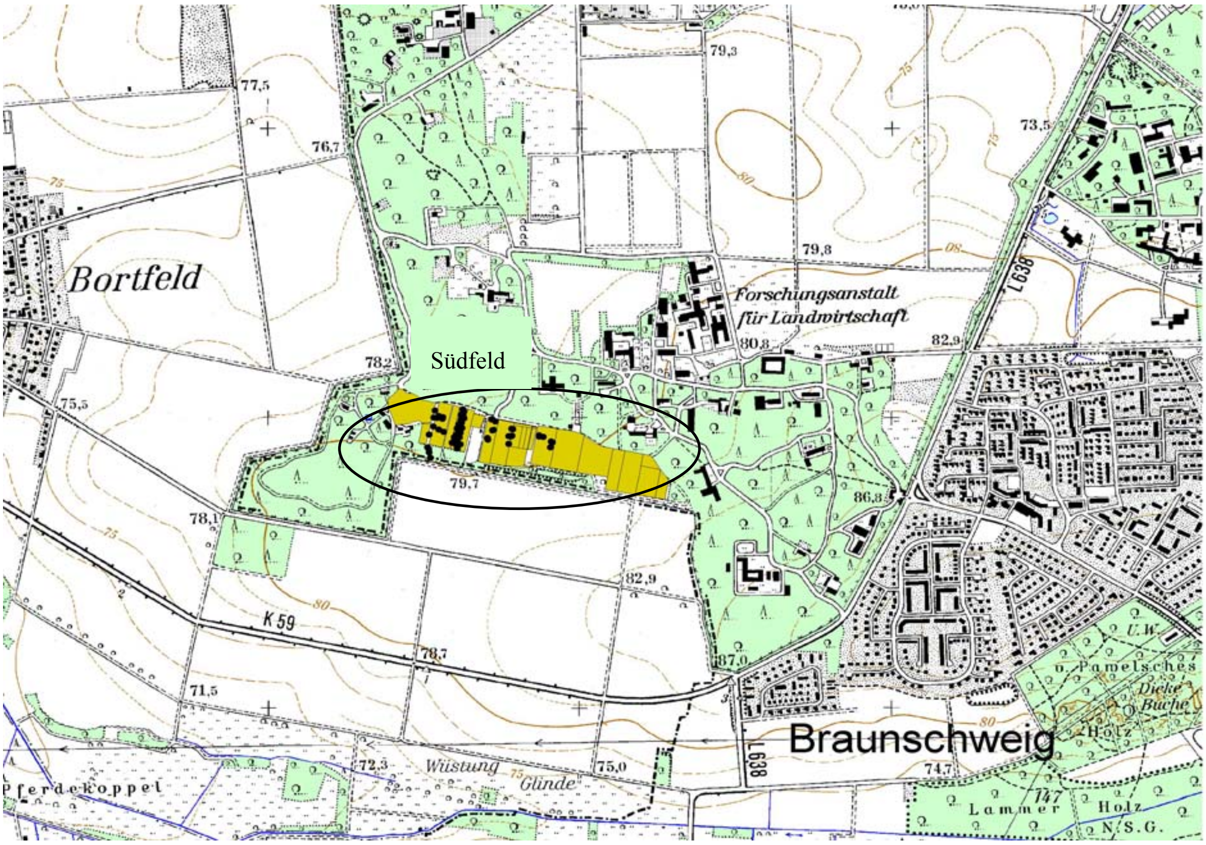


Fig. 2.1**:** Location of Südfeld of the Institute of Crop and Soil Science in Braunschweig

The climate in Braunschweig has frequent changes in temperature, humidity and winds. It is commonly a typical temperate climate. The average annual temperature is around 9.0 ^{0}C and the mean sum of sun hours about 1400 h. The mean annual precipitation in Braunschweig is 619 mm. The precipitation rates and temperature means during the experimentation period are shown in Figure. 2.3. The soil type is a Cambisol with a loamy sand soil texture (<6.5% clay; >47% sand). It has a low water retention capacity and high rates of leaching. The pH ranges from acid (4.8) to moderately acid (5.5).

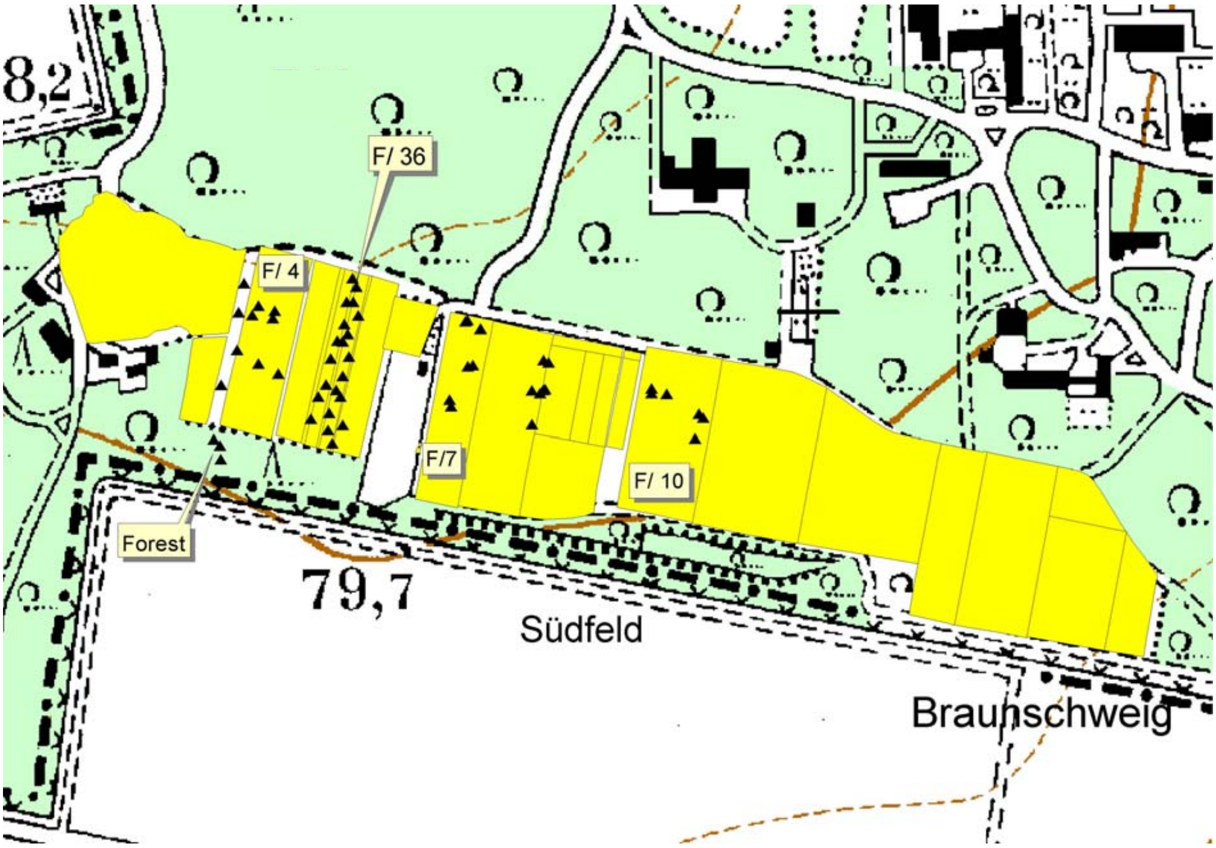


Fig. 2.2: Location of the experimental fields and the test plots (Δ) in Braunschweig

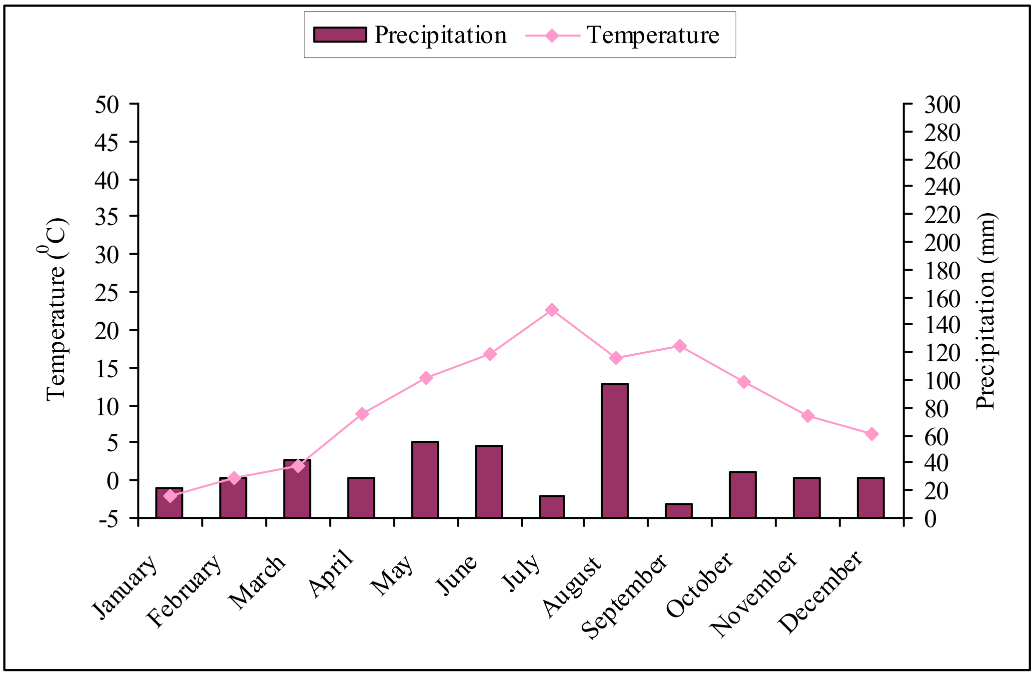


Fig. 2.3: Precipitation and temperature in Braunschweig during the experimentation period (2006)

Experimental design

Field trials were conducted during spring and fall time in the year 2006 as illustrated in Table 2.2 and Table 2.3.

Tab. 2.2: Experimental design at Braunschweig fields during fall season (2006)

Field	Plot	Treatments	N	P	K	Organic	Cultivation	Crop
			(kg ha^{-1})			(t ha^{-1}DM)		
36	4	NPK	250	45	120	0	Conventional	Winter rapeseed
	10	Manure	0	0	0	12.8	Conventional	
	12	NPK+Manure	100	45	120	12.8	Conventional	
4	1.3	NPK+Manure	40	30	120	4.8	Conservation	Field beans
	2.3	NPK+Manure	40	30	120	4.8	Conventional	

Tab. 2.3: Experimental design at Braunschweig fields during spring season (2006)

Field	Plot	Treatments	N	P	K	Organic	Cultivation	Crop
			(kg ha^{-1})			(t ha^{-1}DM)		
36	4	NPK	200	40	100	0	Conventional	Winter barely
	10	Manure	0	0	0	12.8	Conventional	
	12	NPK+Manure	80	40	100	12.8	Conventional	
10	A	NPK	160	40	120	0	Conventional	Winter wheat
	B	NPK+ MBM	80	90	120	1.4	Conventional	
7	32	NPK+Manure	180	50	166.3	4.8	Conventional	Winter wheat
	30	NPK	150	50	166.3	0	Conventional	
	23	NPK+Manure	150	50	166.3	4.8	Conservation	
	1	NPK	120	20	100	0	Conservation	
* Succession	G	----	0	0	0	0	-	grass
Forest	-	-----	0	0	0	0	-	litter

MBM = Meat and Bone Meal

Arable land “A” = test plot “A” of Field No. 10

Arable land “B” = test plot “4” of Field No. 36

* Succession = natural succession

Natural succession is a land covered with natural grass for several years without any management.

Permanent grassland is a land with grass under management.

Crop rotation

The crop rotation was of cereals, rapeseed, sugar beets and legumes. A summary of the crop rotations for the former six years is given in Table 2.4.

Tab. 2.4: Crop rotations applied at Braunschweig fields in the period (2001-2006)

Field	2001	2002	2003	2004	2005	2006
36	Field beans	Winter barley	Winter rapeseed	Winter wheat	Field beans	Winter barley
10	-----	---------	Maize	Summer barley	Sugar beets	Winter wheat
7	Winter wheat	Field beans	Winter barley	Winter rapeseed	Maize	Winter wheat
4	Winter barley	Winter rapeseed	Winter wheat	Maize	Winter wheat	Field beans

2.1.2 Mariensee

Location and climate

Mariensee (E 9^0 28`, N 52^0 33') is located in the Weser-Aller alluvial plain in the state of Lower Saxony, Germany (Fig. 2.5). Predominant soil types are Luvisol and Fluvisol. Mariensee has high rainfall where the average annual precipitation is 680 mm. Most of the rainfall occurs in the period from March until June. The mean annual temperature is about 8.9 ^{0}C. The highest numbers of sunshine hours are in May. Precipitation and temperature in Mariensee during the experimentation time are shown in Figure 2.4.

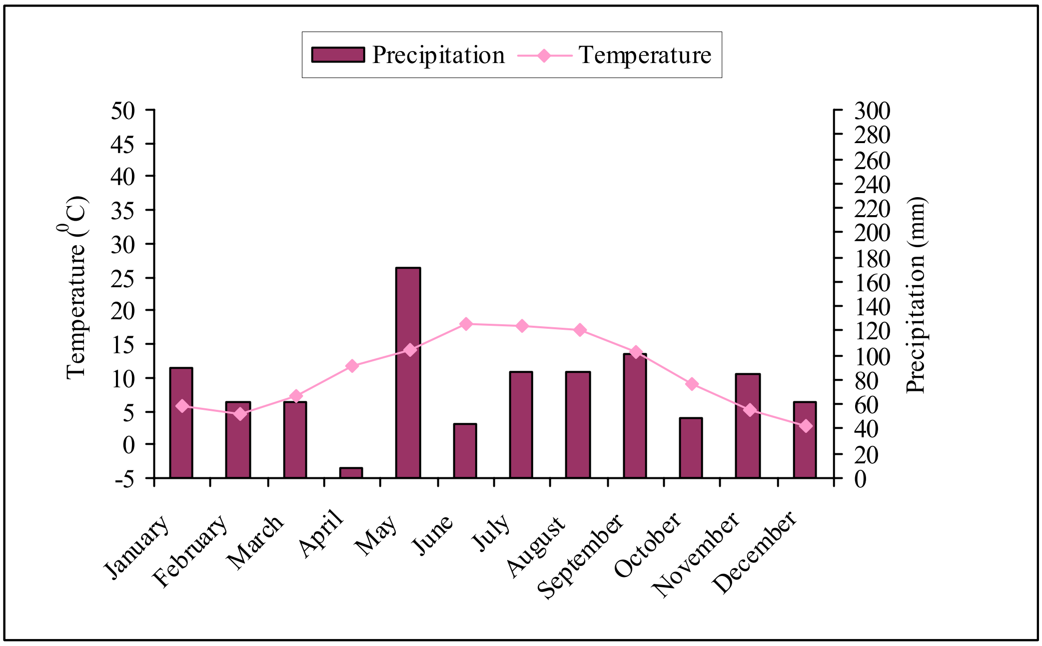


Fig. 2.4: Precipitation and temperature in Mariensee during the experimentation period (2007)

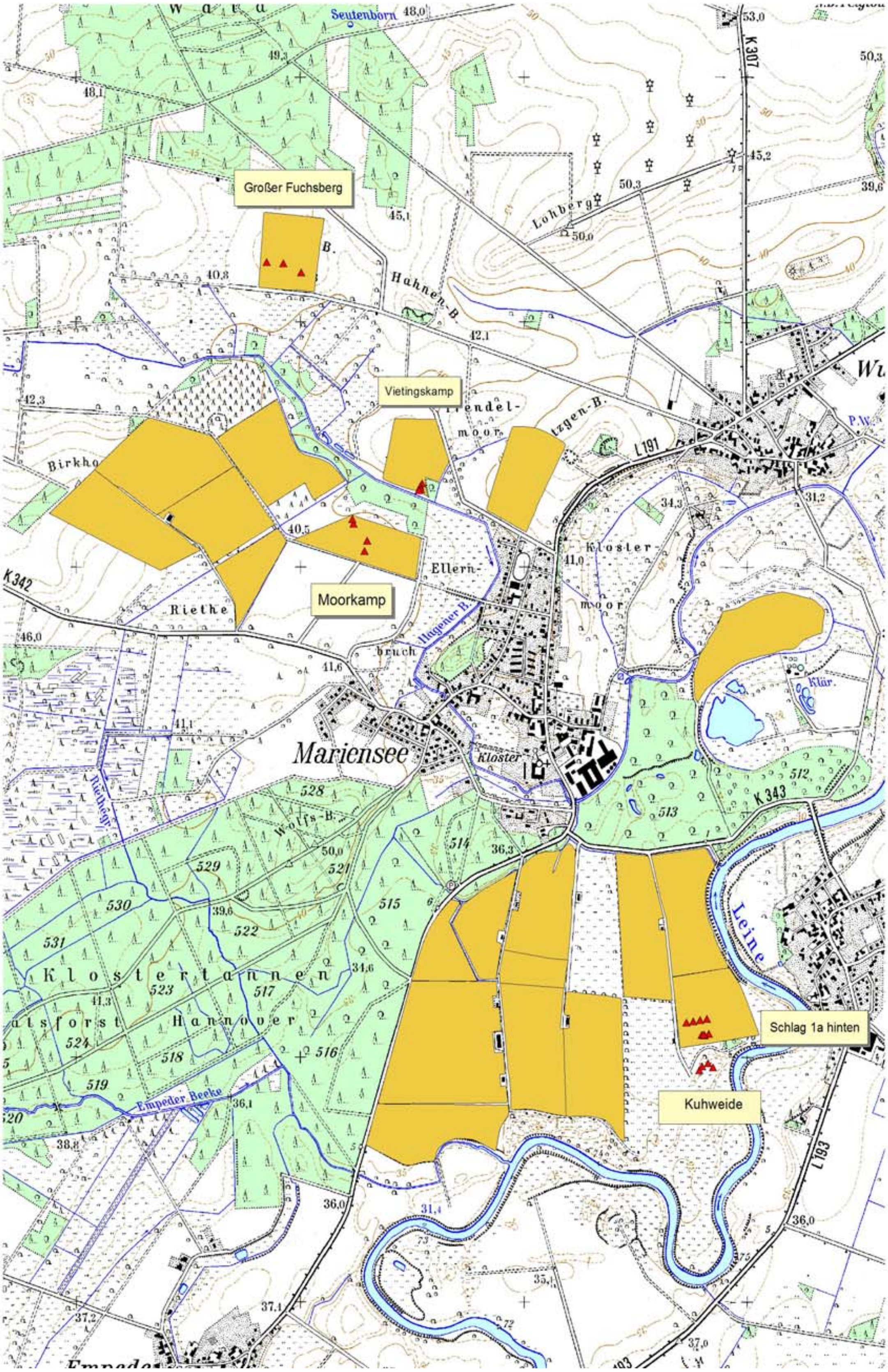


Fig. 2.5: Location of the experimental fields and the test plots (Δ) in Mariensee

Experimental design

Field trials were conducted during fall time in the year 2007 as shown in Table 2.5.

Tab. 2.5: Experimental design at Mariensee fields during fall season in the year 2007

Field	Plot	Treatments	N	Organic	Cultivation	Crop
			(kg ha^{-1})	(m^3 ha^{-1})		
Schlag1	S	N	180	0	Shallow	Winter wheat
	D	N	180	0	Deep	Winter wheat
Vietingskamp	-	-	0	0	--------	grass
grassland	-	N	80	0	--------	grass
Moorkamp	-	Liquid manure	0	22	Conventional	Winter barley
Gr.Fuchsberg	-	Liquid manure	0	25	Conventional	Winter barley

Crop rotation

Major crops grown in Mariensee were winter barley, winter wheat, oats, forage maize, peas and sugar beets. The crop rotations at Mariensee fields for previous years are listed in Table 2.6.

Tab. 2.6: Crop rotations applied at Mariensee fields in the period (2002-2006)

Field	2002	2003	2004	2005	2006
Schlag1	Winter barley	Summer barley	Winter rapeseed	Winter rapeseed+ winter wheat	Winter wheat
Moorkamp	Winter barley	Peas	Winter barley	Forage maize	Winter wheat
Gr. Fuchsberg	Peas	Winter wheat	Winter rye	Winter barley	Peas
Vietingskamp	Permanent grassland				
Grassland					

2.1.3 Trenthorst

Location and climate

Trenthorst (E 10^0 31`, N 53^0 47') is located in northern Germany. The selected experimental fields belong to the Institute of Organic Farming. The experimental farm is an adjacent flat land area in hilly East Holstein (Fig 2.6).

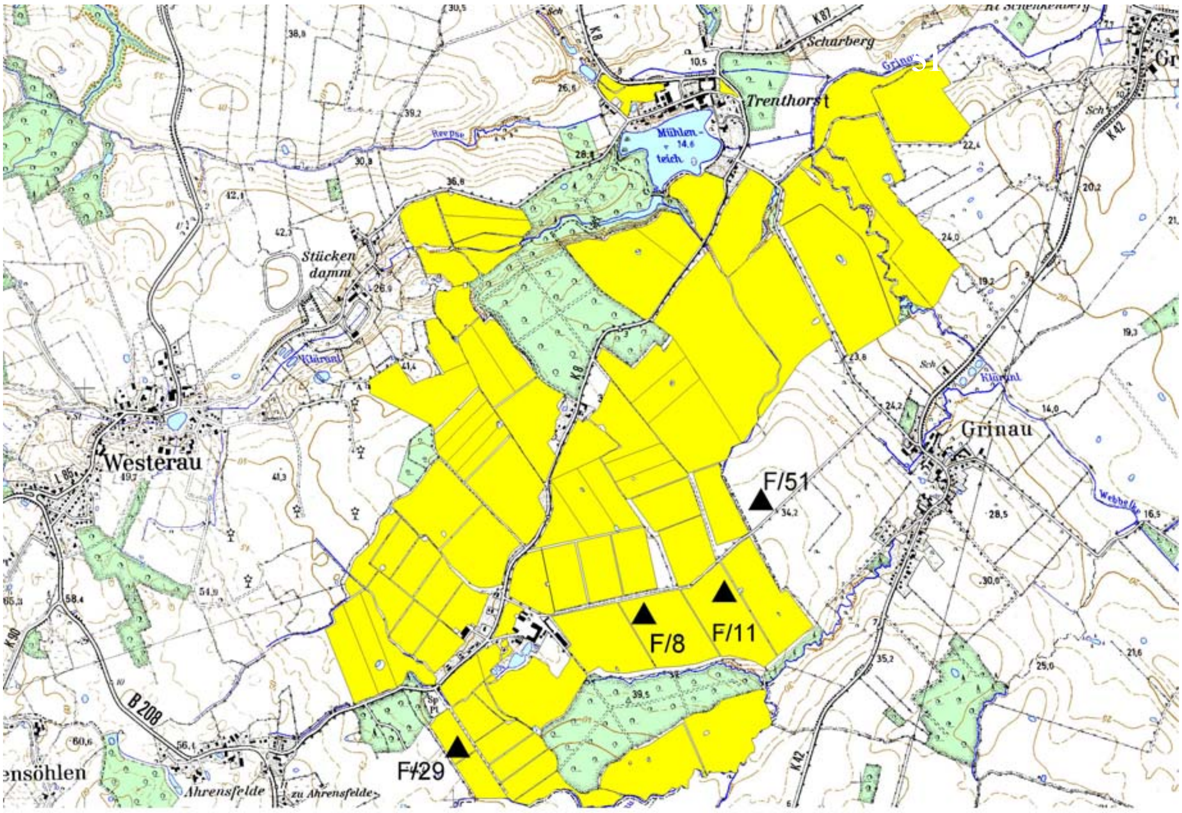


Fig. 2.6: Location of the experimental fields and the test plots (Δ) in Trenthorst

The average annual rainfall in Trenthorst is 740 mm, and the average annual temperature is 8.7 ^{0}C. The precipitation and temperature means during the experimentation periods (2006, 2007) are presented in Figure 2.7 and Figure 2.8. The soil type is a Luvisol with a sandy loam soil texture. Soil organic matter is about 2.1% and the pH is around 6.4 as average value for all plots.

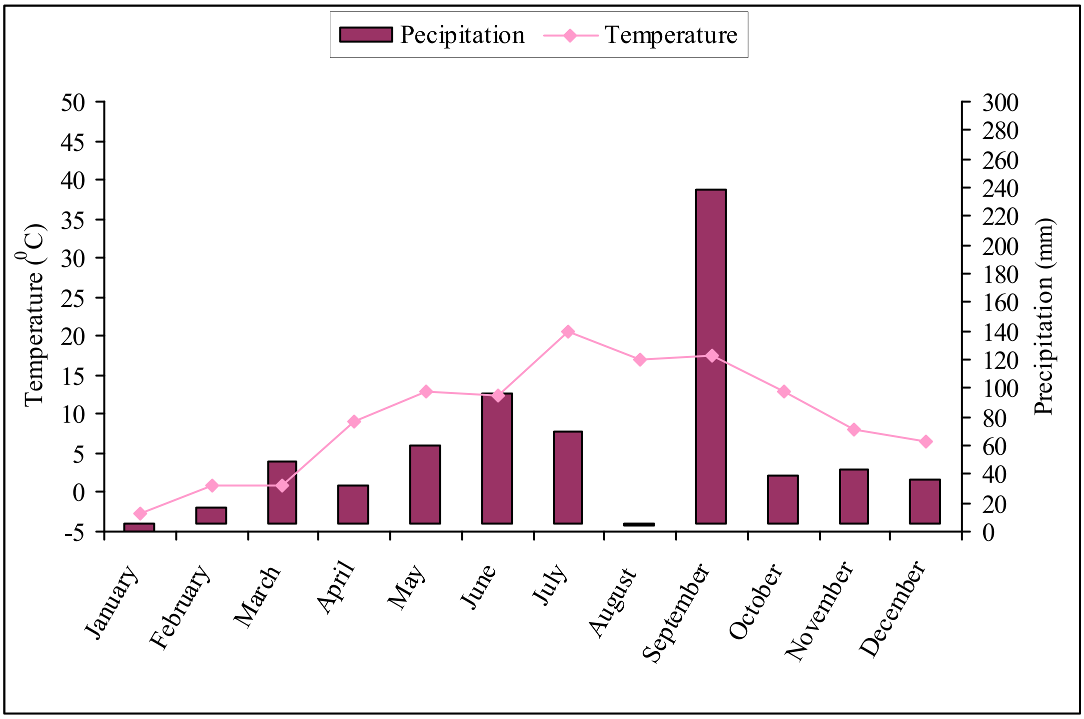


Fig. 2.7: Precipitation and temperature in Trenthorst during the experimentation period (2006)

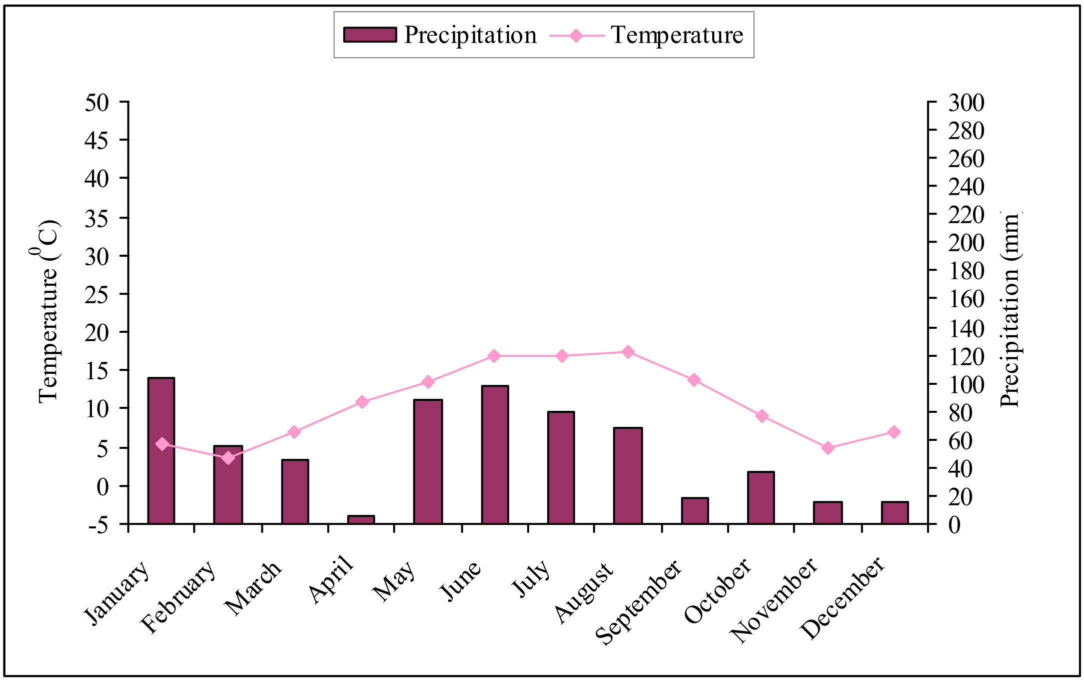


Fig. 2.8: Precipitation and temperature in Trenthorst during the experimentation period (2007)

Experimental design

Experiments were designed during spring time in the years 2006 and 2007. Their design is shown in Table 2.7 and Table 2.8.

Tab. 2.7: Experimental design at Trenthorst fields during spring season (2006)

Field	Treatments	N	P	K	Organic	Cultivation	Crop
		(kg ha^{-1})			(m^3 or t ha^{-1})		
51	Slurry+NK	168.2	0	80	18 (s)	Conservation	Winter wheat
29	Liquid manure	0	0	0	50 (lm)	-	Grass
11	Liquid manure + fym	0	0	0	71.63(lm) + 3.72 (fym)	Conservation	Triticale
8	Liquid manure + fym +lime (75 kg ha^{-1})	0	0	0	29 (lm) + 16.29 (fym)	Conservation	Winter wheat

(lm) = Liquid manure (m^3ha^{-1}) whereas (fym) = farmyard manure (t ha^{-1})
(s) = slurry (m^3ha^{-1})

Tab. 2.8: Experimental design at Trenthorst fields during spring season (2007)

Field	Treatments	N	P	K	Organic	Cultivation	Crop
		(kg ha^{-1})			(m^3 or t ha^{-1})		
51	Slurry+NK	148	0	80	10 (s)	Conservation	Winter barley
29	Liquid manure	0	0	0	44.95 (lm)	-	grass
11	Liquid manure	0	0	0	66.95 (lm)	Conservation	Clover+grass
8	Liquid manure+ fym	0	0	0	54.32 (lm) +49.2 (fym)	Conservation	Faba beans+ Oast

(lm) = Liquid manure (m^3ha^{-1}) whereas (fym) = farmyard manure (t ha^{-1})
(s) = slurry (m^3ha^{-1})

Crop rotation

The investigated fields in Trenthorst were cultivated with various plants organized into specific crop rotations. The sequence of the different crops involved in the crop rotations during 2001 to 2006 is shown in Table 2.9.

Tab. 2.9: Crop rotations applied at Trenthorst fields in the period (2001-2006)

Fields	2001	2002	2003	2004	2005	2006
51	Winter barley	Winter rapeseed	Winter wheat	Winter barley	Winter rapeseed	Winter wheat
8	Winter barley	Peas/Spring barley	Triticale with undersown clovergrass	Clover grass	Clover grass	Winter wheat
11	Winter barley	Clover grass	Winter wheat	Oats/Faba beans	Peas/Spring barley	Triticale
29	Permanent grassland					

2.2 *Soil sampling procedures*

Soil samples were taken during spring season in Braunschweig and Trenthorst and during fall season in Mariensee. A sampling point, within a radius of >1 m, was chosen in each experimental plot of the test fields in Braunschweig and Trenthorst. Soil samples required for chemical analysis were taken directly from the pit from 2-8, 10-16, 18-24, 26-32, 34-40, and 42-48 cm soil depth. Samples needed for investigating soil physical and biological properties were taken from two depths 0-30, 30-60 cm using an auger sampler. Samples were air-dried and passed through a 2 mm sieve prior to analysis. Samples concerning soil biological analysis were kept in polyethylene bags in a cool room at 4 ^{0}C to conserve their moisture. In addition, undisturbed soil core samples were taken from several successive depths using metal ring-tubes or cylinders.

2.3 *Soil chemical analysis*

All analytical methods were carried out on air-dried soil samples < 2 mm. The employed chemical methods are summarized in Table 2.10.

Tab. 2.10: Methods for soil chemical analysis

Parameter	Method
Total carbon	Dry combustion method (LECO EC-12® , Model 752-100) (Carter, 1993)
Total nitrogen	Kjeldahl extraction method (VDLUFA-Methode, Hoffmann, 1991)
Available P and K	Calcium-acetate-lactate (CAL)-extraction method, P was determined by spectrophotometry; K was determined by flamephotometry (Schüller, 1969).
Mg	$CaCl_2$-extraction and determination by Atomic Absorption Spectroscopy (VDLUFA-Methode, Hoffmann, 1991)
pH	Potentiometrically in 0.01M $CaCl_2$ suspension using a Methrohm 605 pH meter with glaselectrode (VDLUFA-Methode, Hoffmann, 1991)
$CaCO_3$	Volumetrically by means of "Calcimeter" (König, 1923)
Soil organic matter	Calculated from data of $CaCO_3$ and total carbon

2.4 Soil biological analysis

2.4.1 Sampling and investigation of earthworms

Earthworms were sampled from the studied sites according to International Standard (2003) and Lee (1985). The earthworms sampling method was based on the combination of hand-sorting worms from a certain area (0.25 m^2) and worms extraction from soil by applying formalin solution. Sampling was done in springtime when worms were not forced to deeper soil horizons by low soil moisture or high temperature. Four points were selected at each trial plot to extract earthworms. At each point, a square of 50*50 cm was marked, herbs and litter were removed from the soil surface and the upper soil was removed using a spade up to a depth of 20 cm from that area. The excavated soil was spread on a plastic sheet and searched carefully by hand for earthworms. Big earthworms were collected by hand using plastic gloves and small worms using forceps. During the hand-sorting, 5 L of 0.5% formalin solution was carefully applied, gradually through couple doses, into the hole from which the top soil has been removed for hand-sorting. The hole was carefully observed during the application of formalin and the earthworms appearing on the soil surface of the sampling hole were collected by forceps and washed in a pot with water (Photo. 1).

Photo. 1: Extraction of earthworms by formalin application

The sampling finished 30 minutes after the application of the last dose of formalin solution and afterwards, the excavated and searched soil was returned to the original sampling hole. All collected earthworms were stored in 500 ml plastic vessels with a quantity of the same soil. The vessels were labelled and transported to the laboratory.

Earthworm investigation was performed at the laboratories of the Institute of Crop and Soil Science, which is related to Julius Kuehn Institute (JKI), in Braunschweig. Ecological groups, biomass and age structure of sampled earthworms were investigated according to Lee (1985). Earthworms have been classified into three ecological groups basing on both color and size. The first group called “Epigeic” surface dwelling species. They live at soil surface, usually in litter layer. They have no burrows and they are strongly pigmented, their color seemed dark brown to reddish brown. They have small size that ranges between 2-5 cm (Photo. 2).

Photo. 2: Epigeic earthworms sampled by hand sorting (Worms seemed very dark colored)

The second group was "Endogeic" or topsoil species. They live in topsoil layer and often make permanent horizontal burrows. They are not pigmented and they seemed yellowish, whitish and somewhat pink. They have medium size, between 3-12 cm, (Photo. 3).

Photo. 3: Endogeic earthworms sampled by hand sorting (Worms appeared with light color)

The third group was "Anecic" or what is known as subsoil species. They live very deeply in subsoil up to 2 meters and produce extensive and permanent vertical burrows.

They are sharply pigmented with reddish brown color especially on the head part. They are very large in size that came to 8-20 cm (Photo. 4).

Photo. 4: Anecic earthworms extracted by formalin application (The front part of body was colored more than the other parts, adult worms have a clitellum near the head)

Earthworm biomass was determined using a big glass plate filled with water. Each worm was washed in water for 5 minutes, rapidly dried using soft paper and then directly weighed by a precise balance. 10 % of the weight obtained by balance was subtracted as the weight of soil content in the gut and hence, the remaining weight was considered as the fresh weight of earthworm. Consequently, earthworm biomass was expressed as a fresh weight of the population per square meter.

The age structure was identified using the dissecting lens. Each worm was let to swim in a glass plate filled with water and carefully examined under the lens. Adult earthworms possessed a collar called clitellum in the front part of the body (Photo. 4), whereas juvenile individuals had no clitellum.

The total abundance of earthworms in each trial plot was calculated by summing the numbers of worms sampled from the four holes, each hole equalled 0.25 m^2, and expressed as number of individuals per square meter.

2.4.2 Dehydrogenase activity (DHA)

A dehydrogenase (DHA) assay was used to determine microbial activity in soil. The dehydrogenase activity was measured according to the method suggested by Thalmann (1968) and modified by Malkomes (1991). This method is based on the reduction of 2,3,5-

triphenyl tetrazolium chloride (TTC) to a red colored triphenyl formazan (TPF). In this way, 5 test tubes were used for each sample, 4 as replicates and one as control. 2 g fresh soil were placed in each replicates tube and suspended in 2 ml triphenyltetrazolium chloride solution (TTC) whereas, 2 g fresh soil plus 2 ml Tris buffer were put in the control tube and then all tubes were incubated for 24 hours at 30 ^{0}C. After 24 hours, 10 ml acetone was added to each tube (replicates and control) and all the tubes were shaken in the darkness by hand every 30 minutes for 2 hours. Thereafter, all soil samples in the tubes were filtrated through Whatman paper No. 595 in new tubes and measured photometrically at 546 nm by means of a spectrophotometer. Dehydrogenase activity was expressed as µg TPF formed / g soil. dry weight.

2.5 *Soil physical analysis*

The main soil physical properties determined in this research work as well as the methods employed are shown in Table 2.11.

Tab. 2.11: Methods employed for the determination of soil physical properties

Parameters	Method
Soil texture	Pipette method (ISO, 1998): Stored samples Hydrometer method (ISO, 1998): Fresh taken samples
Dry bulk density	Undisturbed soil core samples, gravimetric (Culley, 1993)
Aggregate stability	Wet sieving method (Angers and Mehuys, 1993)
Pore size distribution and Retention function	Sand/ kaolin box, calculation of volumetric soil water content for different pF-values (matrix potential). (Carter and Ball, 1993)
Soil water content	Gravimetric method (Topp, 1993)
Penetration resistance	Penetrologger, (Eijkelkamp)
Plant cover	Defined metal frame, visual description, photos
Infiltration	Hood infiltrometer (UGT, 2004)

2.5.1 *Soil texture*

Particle size distribution, or soil texture, analysis for the investigated soil samples was carried out using the Hydrometer method. The principle of the Hydrometer method is based on combination of sieving and sedimentation starting from air-dried soil. For this, 50 g for clay soils, 100 g for sandy soils of 2-mm air-dried soil were put in a 650 ml beaker. 30 ml of distilled water was added to the sample to get thoroughly wet. 30 mm of 30% volume fraction hydrogen peroxide solution was added for destruction of soil organic matter and the contents were gently mixed using the glass rod. The vessel was covered with a glass cover and left overnight. Thereafter, the vessel was placed on the hotplate and warmed gently. 25 ml of 1 mol/l calcium chloride solution was added as aid for flocculation. The content was strongly mixed with 250 ml water and washing procedure was repeated until all decomposed organic matter was destroyed. The washed residue was quantitatively transferred to a centrifuge bottle and sufficient water was added until the total volume came to 200 ml. 25 ml of dispersing agent (Na- hexametaphosphate 5%) was added and the bottle was shaken for 18 hours on an end-over-end shaker. The dispersed suspension was quantitatively transferred from the centrifuge bottle onto the 0.063 mm sieve. The soil was wet sieved using a jet of water and rubbing with a stiff brush until the water became clear. The residue on the sieve was washed into an evaporating dish and completely dried in an oven at 105 ^{0}C and then cooled and resieved on the sieves <2 mm down to 0.063 mm. The fractions retained on each sieve were weighed and the proportion of sand particles was calculated. Afterwards the suspension, passing the 0.063 mm sieve, was transferred into a measuring cylinder and made up to 1 litre with water. Then the cylinder was firmly closed with a stopper and shaken thoroughly until all the sediment was suspended. The cylinder was placed upright in a water bath at temperature between 20 ^{0}C and 30 ^{0}C. 25 ml of the dispersion agent (Na-hexametaphosphate 5%) was put in another cylinder and diluted with water to the volume 1 litre as blank. After 1 hour, hydrometer readings were taken after durations of 0.5 min, 1 min, 2 min, 4 min, 8 min, 30 min, 2 hours, 8 hours and 24 hours from the start of sedimentation. Calculations and results were obtained using the following equations:

$d = d' + z_m$ (Equation 1)

where:

z_m = meniscus correction (mm)

d`= observed hydrometer reading in the soil suspension.

Stokes' law:

$d_P^2 = 18\eta z / (p_S - p_W) g t$ (Equation 2)

where:

d_P = diameter of particle (mm)

η = dynamic viscosity of water at the test temperature (millipascals per second)

z = effective depth at which the suspension density is measured (mm)

p_S = particle density, assumed to be 2.65 Mg m^{-3}

p_W = density of the suspension liquid, taken to be 1Mg m^{-3}

g = acceleration due to gravity, taken to be 981 cm s^{-2}

t = elapsed time (seconds)

$d_m = d' - d_o'$ (Equation 3)

where:

d_m = modified reading of hydrometer

d_o' = hydrometer reading at the top of the meniscus in the dispersant cylinder.

d' = observed hydrometer reading in the soil suspension.

$P\ \% = [d_m/m_t].[\ p_S/(\ p_{S\,-}\ 1)]*100$ (Equation 4)

Where:

P = proportion of particles smaller than a given value of d_P (%)

m_t = total mass of the dry pre-treated soil (gram)

2.5.2 *Dry bulk density*

Soil dry bulk density was determined by taking undisturbed soil samples from 2-8, 10-16, 18-24, 26-32, 34-40, 42-48 cm soil depth using metal ring-tubes (cylinders) with a volume 100 cm^3. From every horizon, 6 replicates were taken. The samples were oven-dried at 105 ^{0}C for 24 hours. Before and after drying, the samples were weighed. Soil dry bulk density was calculated as the ratio of the mass of oven-dried solids to the bulk or total soil volume according to the following equation:

Dry bulk density (g cm^{-3}) = weight of dried soil (g) / total volume of soil (cm^3) (Equation 5)

2.5.3 *Soil aggregate stability*

Aggregate stability was determined for topsoils (0-25 cm) and subsoils (25-50 cm) using a wet sieving apparatus. Stability measurement in this method depends on calculating the proportion of aggregates of a given size (1 to 2 mm) which do not break down into units smaller than a specific size (250 µm) when immerged into water (Photo. 5).

Photo. 5: Soil aggregate stability determination using a wet sieving apparatus

4 grams of 1-2 mm air-dried aggregates were put into each sieve and pre-moistened with distilled water. The sieves fixed in the sieve holder were placed in the cans filled with distilled water. The machine was run for 3 minutes moving up and down. Unstable aggregates passed through the sieve and settled in the cans underneath the sieves. Afterwards, the cans were removed and replaced by new cans filled with dispersing solution (Na- hexametaphosphate 0.2%). The machine was run again and sieving continued until all stable aggregates has gone through the sieve and assembled in the cans. Only sand particles and root fragments were left on the sieve. Both groups of cans were completely dried in the oven at 110 ^{o}C for 24 hours. After that, the cans were weighed and the weight of aggregates in each can was calculated by subtracting the weight of can from the weight of can plus soil. A blank running only with the dispersing agent was subtracted from sample weight. The wet aggregate stability equalled stable aggregates weight divided by the sum of stable aggregates and unstable aggregates weights.

2.5.4 Pore size distribution and water retention

The determination of pore size distribution is dependent on the calculation of volumetric soil water content for different pF-values (Tab. 2.12).

Tab. 2.12: Connections between suction power and pore size (KA4, 1994).

<table>
<tr><td colspan="2">Suction power range</td><td rowspan="2">Equivalent diameter of the pores in µm</td><td rowspan="2">Name of the pores</td><td colspan="2" rowspan="2">Classification of soil water</td><td colspan="3" rowspan="2">Classification of storage capacity</td></tr>
<tr><td>hPa (cm Water column)</td><td>pF- value</td></tr>
<tr><td>< 60</td><td>< 1.8</td><td>> 50</td><td>Large macropores</td><td>Fast mobile</td><td rowspan="2">Free water</td><td colspan="2">Air capacity or storage capacity for ground and back water</td><td rowspan="5">Maximum water capacity</td></tr>
<tr><td>60 - 300</td><td>1.8 - 2.5</td><td>50 - 10</td><td>Narrow macropores</td><td>Slowly mobile</td><td rowspan="2">available field capacity</td><td rowspan="4">Field capacity</td></tr>
<tr><td>300- 15000</td><td>2.5 - 4.2</td><td>10 - 0.2</td><td>Mesopores</td><td>Plant available</td><td rowspan="3">Fixed water</td></tr>
<tr><td colspan="5">Permanent wilting point</td><td></td></tr>
<tr><td>>15000</td><td>> 4.2</td><td>< 0.2</td><td>Micropores</td><td>Not plant available</td><td>Dead water</td></tr>
</table>

Soil water retention characteristics or pF curves were determined using the sand/kaolin box method supplemented by a pressure chamber. Undisturbed soil core samples were taken using metal cylinders from several soil horizons (Chapter 2.4.2). These excavated core samples were wrapped in plastic bags to prevent evaporation and to provide protection during transport. To reduce macro fauna activity, they were stored at 4^0 C. In the laboratory, the samples were placed in the sand/kaolin box, saturated and subsequently balanced at a specific moisture tension. After two weeks, samples were weighed. Accordingly, increasing moisture tension was applied to the samples. The variation in moisture tension was obtained by creating a series of pressures. Weighing the samples after each balance adjustment resulted in the volumetric water content for each moisture tension. At last, samples dried up in the oven at 105^o C for 24 hours. The difference between dried weight and fresh weight reflects the moisture content, or water retention, for each water tension.

2.5.5 Soil water content

Soil water content was determined gravimetrically. Soil core samples taken by cylinders from several soil depths were used to determine soil moisture content. These samples were fresh weighed and then oven-dried at 105 ^{0}C for 24 hours and reweighed. Soil moisture e.g. soil water content was calculated as the mass of water lost as a percentage of the mass of the dried soil.

2.5.6 Estimation of plant cover

Plant cover of the studied fields was defined using a metal frame with a size of 0.25 m^2. The vegetation found within this frame was visually described and the percentage of coverage was estimated (Photo. 6).

Photo. 6: Estimation of plant cover using a metal frame (0.25 m^2)

2.5.7 Penetration resistance

The penetration resistance of the soil (soil strength) was measured using a Penetrologger (Photo. 7). It is an instrument devoted to measure the resistance, which a defined cone has to overcome during penetration into the soil. The penetrologger mainly consists of an electronic penetrometer together with data logger for storing and processing measurement data as well as probing rods with different cones. The penetrologger is set for measurement to a depth of 80 cm. The depth reference plate was placed on the ground at the defined measurement point. Then the probing rod ended with proper cone was put through the plate hole on the ground surface and pushed down into the soil. The values for soil resistance to probing rod penetration at each layer of the ground profile were recorded and saved in the data-logger for later processing. The measurement was done with 10 replicates at each measurement point.

Photo. 7: Measurement of soil penetration resistance using a Penetrologger

2.5.8 Infiltration measurement

Infiltration was measured using a Hood Infiltrometer (Photo. 8). It is a device for measuring the soil hydraulic conductivity near the saturated zone in field experiments (Schwärzel and Punzel, 2007). The Hood Infiltrometer consists of a “Marriotte“- water supply with a capacity of 5 litres, a large hood with 24 cm diameter, a small hood with 16 cm diameter, a tension-chamber with 24 cm diameter, and graduated with 25 – 0 – -25 cm. Soil infiltration measurements were conducted with 3 or 4 replicates.

The infiltration measurement sequence starts when a circular shaped hood filled with water is directly placed on the surface of soil (Fig. 2.9). This circular shaped soil surface covered by the hood, which is filled with water, is the source for the infiltration flow. The “Marriotte“- water supply controls and regulates the pressure head in the water-filled hood. The effective pressure head (H) is equivalent to the difference between the pressure value in a U-pipe manometer (Us) and the pressure value in the standpipe of the hood (Hs). H can be calculated directly after taking the readings of both U-pipe manometer and the hood as follows:

$$H = Us - Hs \qquad \text{(Equation 6)}$$

Infiltration measurements depend on the pressure applied in the water-filled hood that is connected to the soil surface.

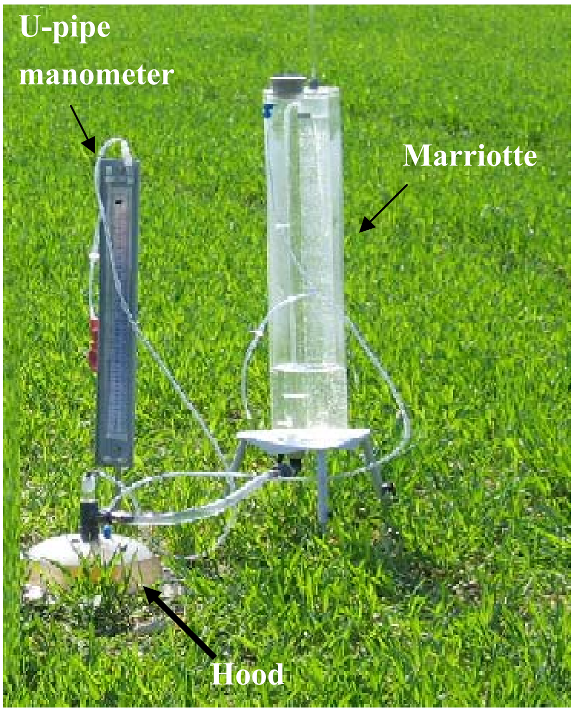


Photo. 8: Infiltration measurement using a Hood Infiltrometer

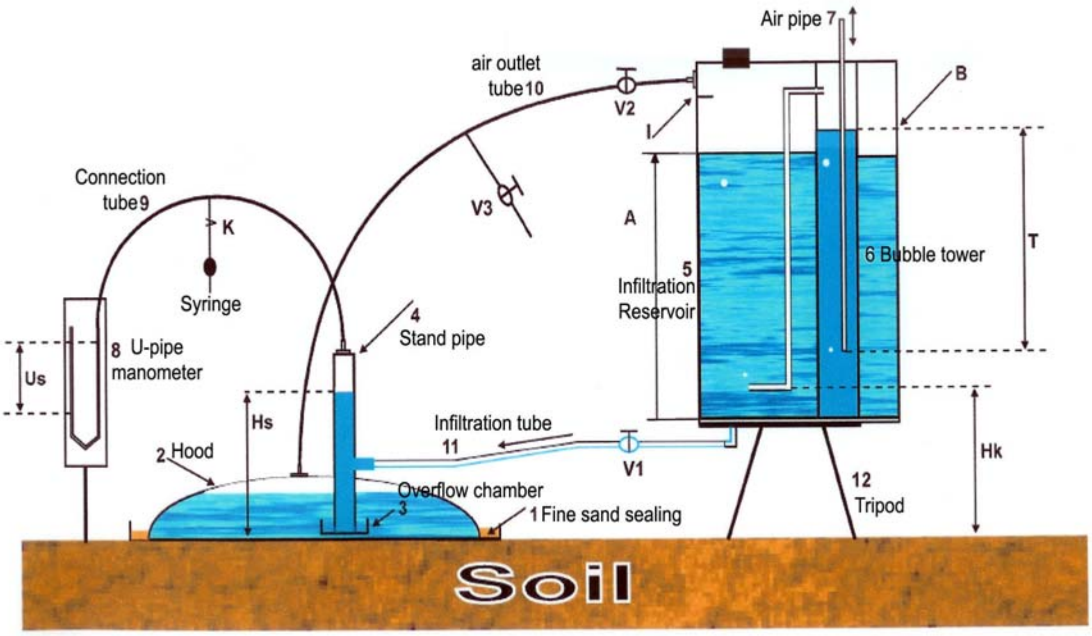


Fig. 2.9: The principle of infiltration measurement using a Hood Infiltrometer (Schwärzel and Punzel, 2007 (modified))

The hood infiltrometer is used for measuring saturated and near saturated soil hydraulic properties as integral information over the soil horizons. Hood infiltrometer measurements do not require any preparation of soil surface. Infiltrometer readings are done within short time. Furthermore, hood infiltrometer measurements have high precision and result in reliable data.

2.6 Statistical analysis

The statistical analyses were accomplished employing the statistical software-package SPSS Version 12 (2003). The significance test of mean difference was performed using LSD and Duncan’s test at significance level 0.05. Regression and correlation analyses were used to identify the relations between the different factors. Factor analysis was used to determine the interactions between the studied factors.

3 Results

In order to contribute to the understanding of the wide variation observed in soil infiltration capacity, it was the objective of this work to investigate the impact of different land use and farming management systems on water infiltration into the soil.

3.1 Infiltration capacity, soil properties and earthworm population in relation to land use

Three land use systems, pine forest, natural succession and arable land were investigated in Braunschweig to evaluate their influence on water infiltration into the soil and selected important soil properties. The arable land investigated comprised mainly the arable land "A" cultivated with winter wheat and the arable land "B" cultivated with winter barley, (see Page 11). The arable land "A" can be characterized as "old" arable land, in use for more than 150 years. The arable land "B" is a deforested land, converted into arable land 60 years ago.
Table 3.1 presents the estimation of soil texture of the investigated land use systems as one main factor for a wide range of processes in soil.

Tab. 3.1: Soil texture analysis of different land use systems (site Braunschweig, 2006)

Soil textural classes	Forest	Natural succession	Arable land	
			A	B
0-30 cm				
Sand (%)	48	36	42	36
Silt (%)	42	57	51	57
Clay (%)	10	7	7	7
30-60 cm				
Sand (%)	51	47	42	50
Silt (%)	42	47	51	44
Clay (%)	7	6	7	6

According to the results shown in Table 3.1, the soil covered by the different land use systems was characterized by a sand content in the range between 40-50 %. In contrast, the clay content was very low (predominantly less than 10 %). The silt content was estimated in the range between 40-60 %. These low textural differentiations allow the comparison of the investigated sites. The soil type of the investigated fields in Braunschweig can be characterized according to the German soil classification system (KA 5) as follows:

	Topsoil		**Subsoil**	
Forest	silty loamy sand	(Slu)	strong silty sand	(Su 4)
Natural succession	sandy silt	(Us)	strong silty sand	(Su 4)
Arable land “A”	sandy silt	(Us)	sandy silt	(Us)
Arable land “B”	sandy silt	(Us)	strong silty sand	(Su 4)

3.1.1 Soil infiltration rate

The soil infiltration rate was strongly related to the different land use systems as shown in Figure 3.1.

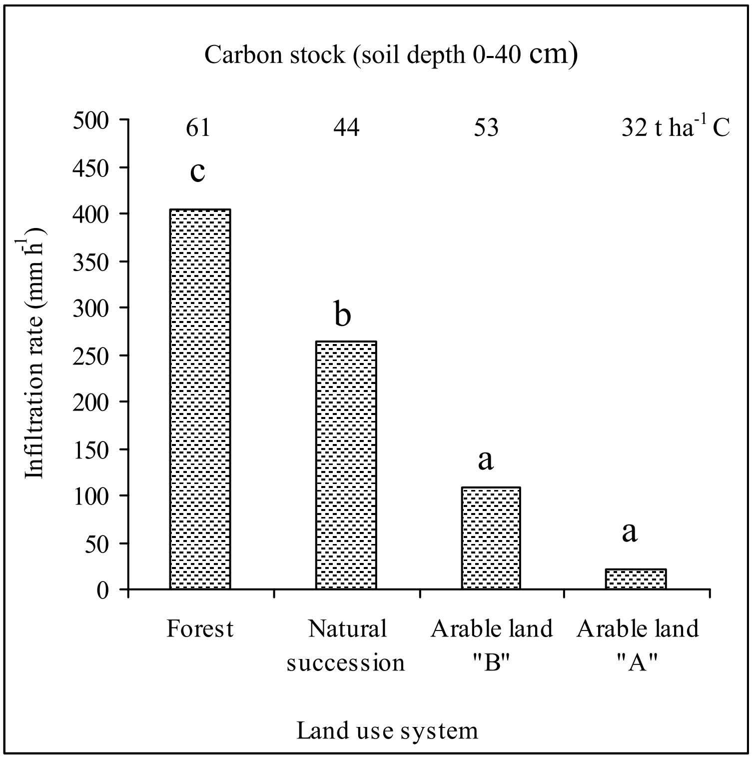


Fig. 3.1: Soil infiltration rate and carbon stock in different land use systems (site Braunschweig, infiltration measurements in April 2006).

Mean values followed by the same letters are not significantly different by Duncan’s test at the 0.05 level.

Soil infiltration rate was found to be significantly greater in forest, due to the large organic layer (humus layer) with the consequence of high retention effect, followed by the natural succession and arable land: forest > natural succession > Arable land “B” ≈ Arable land “A”. The results of the soil carbon stock revealed that the soil infiltration rate was correlated with the soil carbon stock as presented in Figure 3.2.

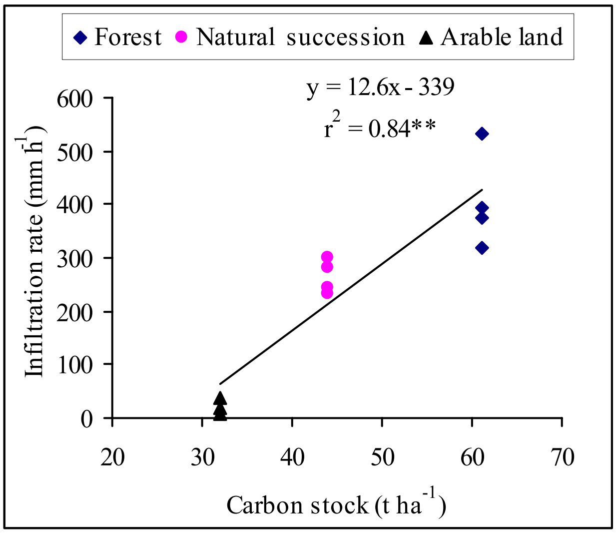


Fig. 3.2: Relationship between soil infiltration rate and soil carbon stock in different land use systems (site Braunschweig, 2006, sampling depth 0-40 cm)
(Significance: *= $p < 0.05$, **= $p < 0.01$, ***= $p < 0.001$, ns = not significant)

It can be concluded that the greater the carbon stock, the greater the infiltration rate of soil.

3.1.2 Dry bulk density

The level of soil dry bulk density is influenced by the different land use systems (Fig. 3.3).

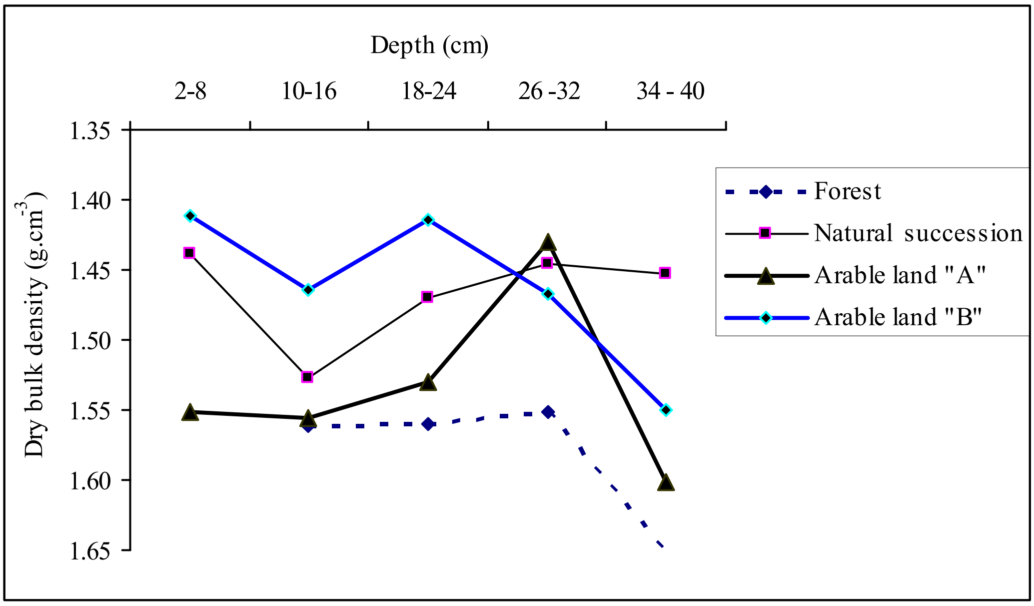


Fig. 3.3: Dry bulk density distribution within the soil profile through several soil depths for different land use systems (site Braunschweig, 2006).

The dry bulk density (g cm^{-3}) in the upper soil layer of forest (organic layer) was very low (0.9, not shown) but increased in the deeper soil layer, due to the horizontal forces caused by the growing tree roots. The reason for the very low value was that the surface layer consisted mainly of an accumulated organic material. The readings of bulk density as shown in Figure 3.3 begin with a value of 1.35. In the natural succession, the bulk density was nearly similar in the top and subsoil layers. This is due to the fact that the natural succession land is under no mechanical stress due to machinery or grazing animals. In the arable land “A”, there were higher bulk densities in all soil horizons except for the fourth one, whereas the arable land “B” had decreased bulk densities in the different soil depths. The differences of bulk density occurring among the arable fields could be attributed to the differences in crop rotations. For instance, the crop rotation applied in the arable land “B” comprised legumes and cereals. Whereas in the arable land “A”, the crop rotation involved no legumes but crops like sugar beets and maize, which exhaust a lot of soil nutrients (compare Table 2.4). The variation of bulk density of the compacted zone at the boundary between lower topsoil and upper subsoil was estimated among the different land use systems (Table 3.2).

Tab. 3.2: Dry bulk density of the compacted zone at the boundary region between lower topsoil and upper subsoil caused by different land use systems (site Braunschweig, 2006)

	Dry bulk density (g cm^{-3})			
Depth	**Forest**	**Natural succession**	**Arable land “B”**	**Arable land “A”**
(26-32 cm)	1.55 b	1.45 a	1.47 ab	1.43 a
(34-40 cm)	1.65 c	1.45 a	1.55 b	1.60 bc

Mean values followed by the same letters are not significantly different by Duncan’s test at the 0.05 level.

At the depth (26-32 cm), the dry bulk density of the natural succession was significantly lower than in the forest. No significant difference was found in the bulk density between the natural succession and arable land. The arable land “A” had a bulk density which was significantly lower than the forest soil. At the depth (34-40 cm), the natural succession soil had a dry bulk density significantly lower than the ones in the forest soil and arable land. It can be attributed to a very low content of soil organic matter and a high content of sand in this depth of the forest soil, as well to a plough pan or traffic sole in the arable land. The bulk density in the arable land “B” was found to be significantly lower than in the forest soil. The relationship between soil infiltration rate and soil dry bulk density was studied only in the natural succession and arable land, but not in the forest (Figure 3.4). That was because the high infiltration rates found in the forest were due to the big extensions of trees roots inside the soil, which result in high lateral water fluxes, producing great increases in soil infiltration rates.

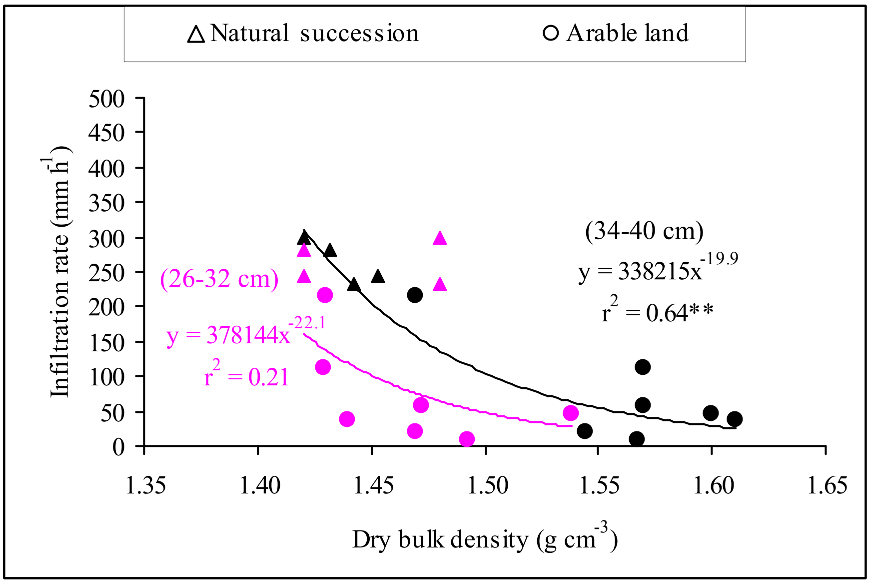


Fig. 3.4: Relationship between soil infiltration rate and soil dry bulk density in different land use systems (site Braunschweig, 2006, sampling depths 26-32 cm and 34-40 cm)
(Significance: $*= p < 0.05$, $**= p < 0.01$, $***= p < 0.001$, ns = not significant)

Figure 3.4 shows that the soil infiltration rate was significantly dependent on the land use. The figure shows also that the relation to soil dry bulk density was stronger at the depth 34-40 cm in comparison to the depth 26-32 cm.

3.1.3 Soil aggregate stability

The soil aggregate stability varied also depending on the different land use systems and it was slightly different between the topsoil and subsoil in each land use system (Fig. 3.5).

The results revealed that the aggregate stability in the topsoil of the natural succession and forest was significantly higher than in the arable land. The following ranking order can be concluded for the aggregate stability of the topsoil: natural succession > forest > arable land “B” > arable land “A”. The soil aggregate stability in the arable land “A” was significantly lower than in the arable land “B”, i.e., so that the soil aggregate stability decreased with the intensity of cultivation. In the subsoil, it was found that no significant differences in the soil aggregate stability were observed between the natural succession and forest, and both were significantly higher than the arable land. There were differences in the soil aggregate stability in each land use system between the topsoil and subsoil (Figure 3.5).

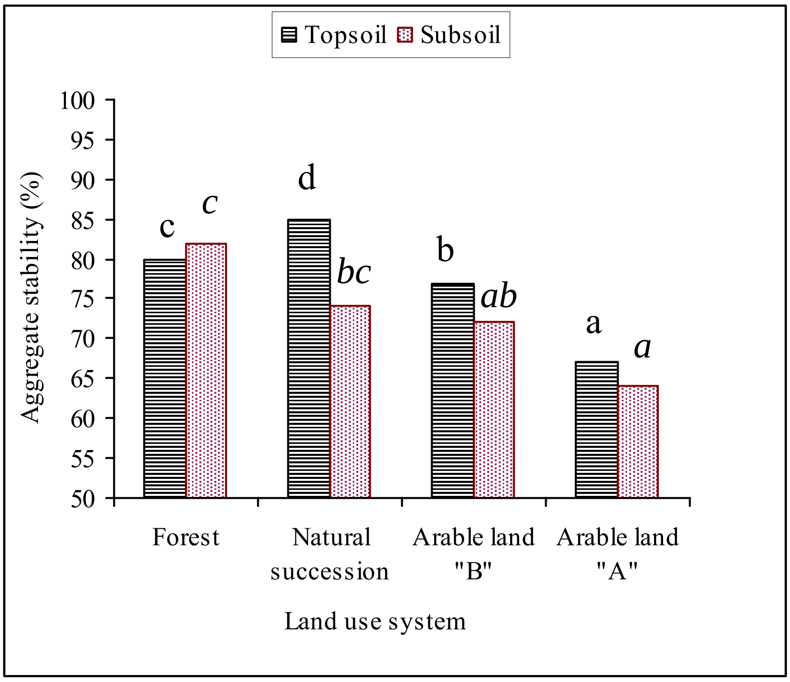


Fig. 3.5: Aggregate stability in topsoil and subsoil of different land use systems (site Braunschweig, 2006, sampling depths 0-25 cm and 25-50 cm)
Mean values followed by the same letters are not significantly different by Duncan's test at the 0.05 level.

In general, the soil aggregate stability was significantly higher in the topsoil compared to the subsoil in the natural succession and the arable land. But in the forest soil, it was higher in the subsoil than in the topsoil. The relationship between soil infiltration rate and soil aggregate stability was studied in the natural succession and arable land (Figure 3.6).

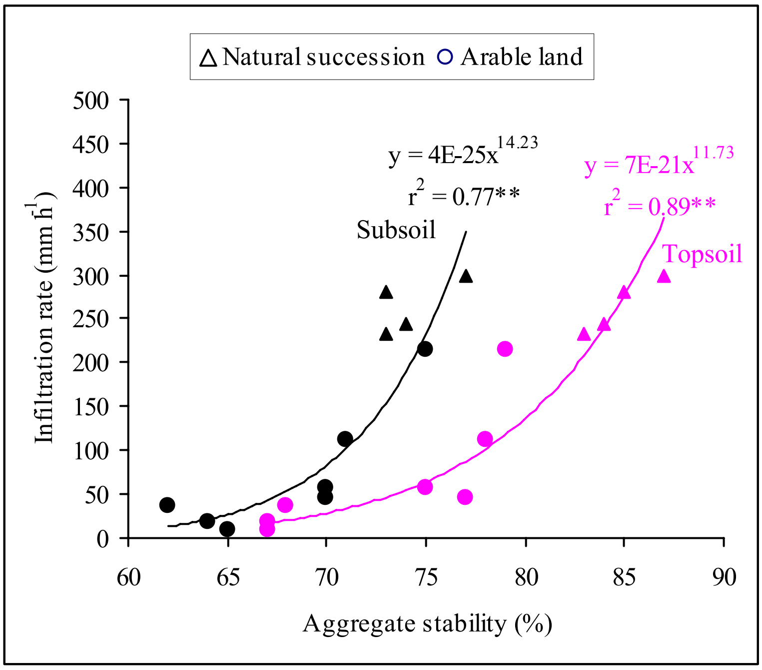


Fig. 3.6: Relationship between soil infiltration rate and soil aggregate stability in different land use systems (site Braunschweig, 2006, sampling depths 0-25 cm and 25-50 cm) (Significance: *= $p < 0.05$, **= $p < 0.01$, ***= $p < 0.001$, ns = not significant)

As can be seen in Figure 3.6, increasing soil infiltration rates were associated with the high soil aggregate stability. The relationship between soil infiltration rate and soil aggregate stability was stronger in the topsoil than in the subsoil. 77 - 89 % of the variability of infiltration rates could be explained by the soil aggregate stability. This means that the aggregate stability is an integral measure for further important soil properties.

3.1.4 Dehydrogenase activity

The results of soil biological analysis showed that the dehydrogenase activity was markedly influenced by the investigated land use systems (Fig. 3.7).

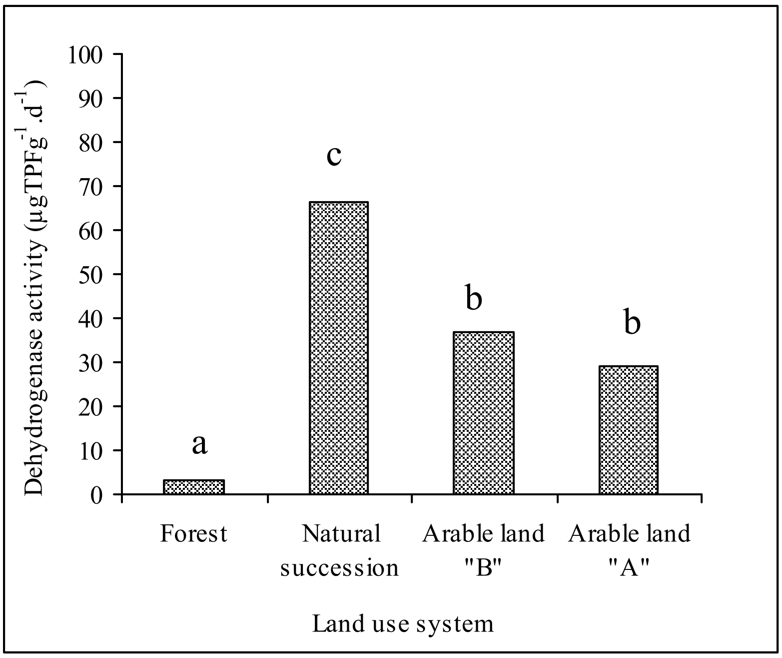


Fig. 3.7: Dehydrogenase activity of soil for different land use systems (site Braunschweig, 2006, sampling depth 0-30 cm)

Mean values followed by the same letters are not significantly different by Duncan's test at the 0.05 level.

The dehydrogenase activity was significantly greater in the natural succession compared to forest and arable land. In the forest soil, the dehydrogenase activity was significantly decreased due to the absence of plant cover on the soil surface. It was observed that the dehydrogenase activity in the arable land "A" and arable land "B" was not significantly different. The following ranking order can be derived: natural succession > arable land "B" > arable land "A" > forest.

3.1.5 Earthworms

The results of earthworm investigation showed that earthworms were entirely absent in the forest soil. That result is attributed to the low soil pH that came to 3.6 preventing earthworm occurrence. The earthworm abundance and earthworm biomass were influenced to a great extent by the different land use systems (Fig. 3.8, Fig. 3.9). Both parameters decreased with increasing cultivation intensity, i.e., the earthworm abundance and biomass were significantly greater in the natural succession as compared to the arable land. The arable land "A" had significantly lower earthworm abundance and biomass than the arable land "B", which is caused by a lower content of carbon in the soil profile (compare Table 3.4).

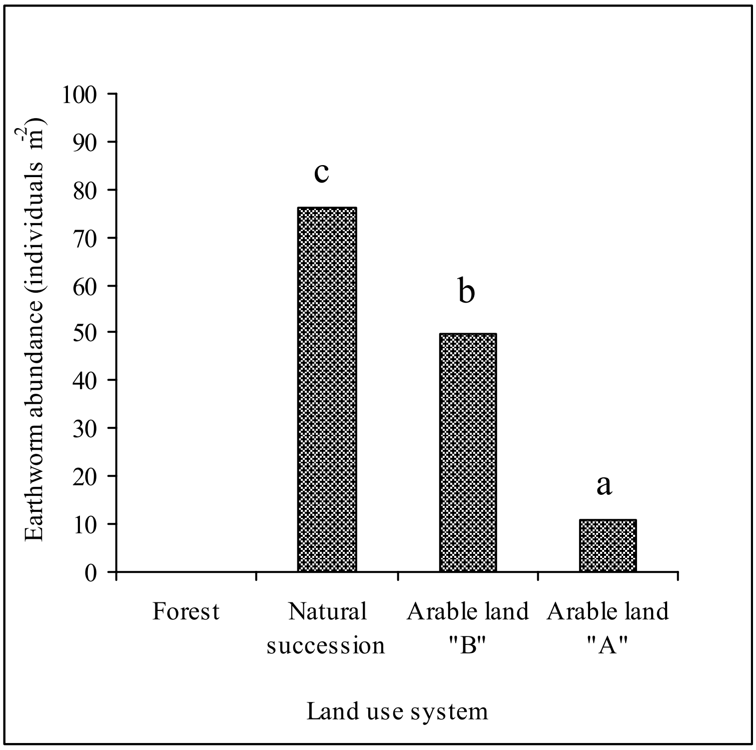


Fig. 3.8: Earthworm abundance for different land use systems (site Braunschweig, 2006)
Mean values followed by the same letters are not significantly different by Duncan's test at the 0.05 level.

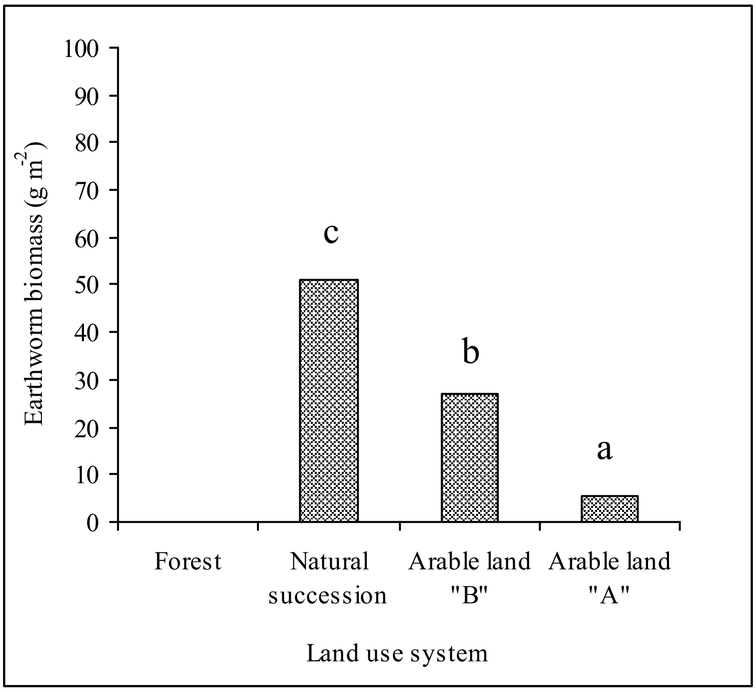


Fig. 3.9: Earthworm biomass for different land use systems (site Braunschweig, 2006)
Mean values followed by the same letters are not significantly different by Duncan's test at the 0.05 level.

In addition, there was a variation in the age structure and the ecological groups of the earthworm populations between the investigated land use systems (Table 3.3).

Tab. 3.3: Age structure and ecological groups of earthworm population for different land use systems (site Braunschweig, 2006)

	Age structure		Ecological groups		
Land use system	**Juvenile**	**Adult**	**Epigeic**	**Endogeic**	**Anecic**
			Individuals m^{-2}		
Forest	-	-	-	-	-
Natural succession	34 b	42 c	12 b	53 c	11 c
Arable land "B"	30 b	20 b	17 c	27 b	6 b
Arable land "A"	6 a	5 a	2 a	8 a	1 a

Mean values followed by the same letters are not significantly different by Duncan's test at the 0.05 level.

The number of adult individuals, epigeic and anecic worms were significantly higher in the natural succession as compared to the arable land. The arable land "A" significantly had the lowest numbers of adult and juvenile worms and only marginal numbers of the epigeic, endogeic and anecic worms (Table 3.3). There was no significant difference observed in the number of juvenile individuals between the natural succession and the arable land "B". In the natural succession soil, it was observed that the number of adults was higher than the number of juveniles. Also, the number of endogeic worms was much higher than the other two groups epigeic and anecic, the numbers of which were approximately similar. In the arable land "B", it was clear that the number of juveniles was higher than the number of adults. In addition, the number of the endogeic worms was higher than the numbers of epigeic and anecic worms but not so much as in the case of natural succession.

Commonly, it was observed that the greater the earthworm abundance the higher the dehydrogenase activity. When the earthworms were absent in the forest, the dehydrogenase activity was very low and tended nearly to be absent. On the other hand, the high dehydrogenase activity in the case of natural succession was accompanied by high earthworm abundance. Even on the arable land, the dehydrogenase activity was higher in the fields with higher earthworm abundance. The relationship between soil infiltration rate and earthworm abundance, as well as the relationship between soil infiltration rate and earthworm biomass, are given in Figures 3.10 and 3.11

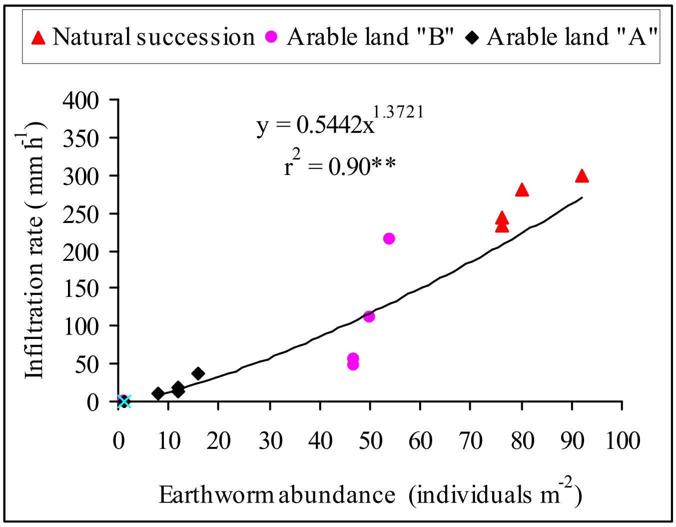


Fig. 3.10: Relationship between soil infiltration rate and earthworm abundance in different land use systems (site Braunschweig, 2006) (Significance: *= $p < 0.05$, **= $p < 0.01$, ***= $p < 0.001$, ns = not significant)

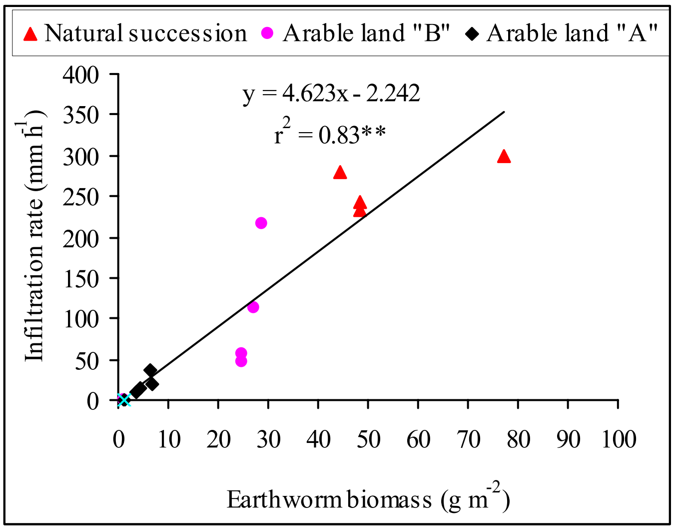


Fig. 3.11: Relationship between soil infiltration rate and earthworm biomass in different land use systems (site Braunschweig, 2006) (Significance: *= $p < 0.05$, **= $p < 0.01$, ***= $p < 0.001$, ns = not significant)

Earthworm abundance and biomass affected the infiltration rate significantly. Increasing infiltration rates were only detectable in soils with a high earthworm activity. It was found that the relationship between earthworm abundance and the infiltration rate was stronger in comparison to earthworm biomass.

3.1.6 Soil chemical properties

Results of soil chemical analysis showed a variation in the content of nutrients related to the different land use systems (Table 3.4, Appendix Tab. 1).

Tab. 3.4: Soil nutrient content for different land use systems (site Braunschweig, 2006, sampling depth 0-8 cm)

Field	Crop	C	N	pH	P	K	Mg
		%	%	----	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}
Forest	---	4.65	0.282	3.3	127	74	32
Natural succession	**Grass**	1.39	0.098	4.6	15	110	31
Arable land "B"	**Winter barley**	1.29	0.086	5.4	51	203	35
Arable land "A"	**Winter wheat**	0.66	0.080	6	92	179	60

The soil N content of forest was, with 0.2 % N, considerably higher than in the natural succession and arable land. The forest soil had P content significantly higher than the natural succession and arable land. However, soil P content ranked as follows in the different land use systems forest > arable land "A" > arable land "B" > natural succession. The soil K and Mg content in the arable land were found to be considerably higher than in the natural succession and forest. No considerable differences in the soil Mg content were noted between the natural succession and forest soil. The soil pH varied in the three systems of land use. It was found that the forest soil was highly acid and had a lower pH than in the natural succession and arable land. Also, the natural succession soil was acidic and its pH was lower than the arable land, which ranged between moderately acidic in the arable land "B" to slightly acidic in the arable land "A". The soil carbon content in forest was significantly greater than in the natural succession and arable land. The soil carbon content of the investigated land use systems can be ranked as follows: forest > natural succession > arable land "B" > arable land "A". The significant relationship between soil infiltration rate and soil organic carbon is given in Figure 3.2.

3.2 Infiltration capacity, soil properties and earthworm population in relation to farming system

Two farming systems were investigated in Trenthorst to evaluate the influence of conventional and organic farming on infiltration rates and further important soil properties. Organic farming does not use any mineral fertilizer and pesticides. The crop rotation is wide and fertilization is only done by organic material (manure). Conventional farming uses mineral and organic fertilizer, pesticides and only limited crop rotation. Both management systems use rotating and non rotating soil management, the technical equipment is similar, so soil compaction is not only an effect of the technical instrumentation. The organic farming system comprised three fields (Field O1 as grassland, Field O2 cultivated with triticale and Field O3 cultivated with winter wheat). The conventional farming system included only Field C1 cultivated with winter wheat.

The results of soil texture analysis for the investigated fields are listed in Table 3.5. These data sets are a basic requirement to assess the infiltration capacity and selected soil properties including earthworm abundance and biomass in relation to farming systems.

Tab. 3.5: Soil texture analysis for fields under different farming systems (site Trenthorst, 2006)

	Conventional farming	**Organic farming**		
Soil textural classes	**C1**	**O1**	**O2**	**O3**
0-16 cm				
Sand (%)	39	46	46	40
Silt (%)	42	36	42	41
Clay (%)	19	18	12	19
16-32 cm				
Sand (%)	39	49	46	40
Silt (%)	41	35	43	42
Clay (%)	20	16	11	18

Based on the results shown in Table 3.5, the texture of the upper topsoil was nearly similar to the texture of the lower topsoil in all studied fields. The differences in the sand and silt content were nearly marginal. The studied sites differ above all in the clay content, with low values on Field O2 and higher values on the other fields. The soil type of the investigated fields in Trenthorst can be characterized according to the German soil classification system (KA 5) as follows:

	Upper topsoil		**Lower topsoil**	
Field C1	weak sandy loam	(Ls2)	weak sandy loam	(Ls2)
Field O1	moderate sandy loam	(Ls3)	strong loamy sand	(Sl 4)
Field O2	silty loamy sand	(Slu)	silty loamy sand	(Slu)
Field O3	weak sandy loam	(Ls2)	weak sandy loam	(Ls2)

3.2.1 Soil infiltration rate

The soil infiltration rate was affected to a varying degree by the organic and conventional farming systems as clarified in Figure 3.12.

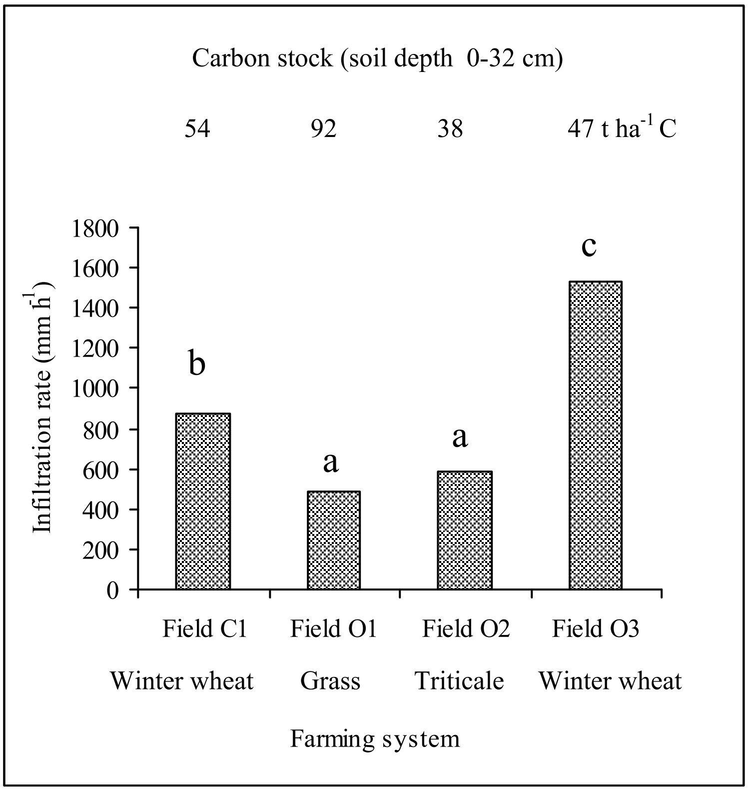


Fig. 3.12: Soil infiltration rate and carbon stock of organic (O) and conventional (C) farming systems (site Trenthorst, infiltration measurement in May 2006)

Mean values followed by the same letters are not significantly different by Duncan's test at the 0.05 level.

The soil infiltration rate in Field O3 was significantly higher than in Field C1, Field O2 and Field O1. No significant differences in the soil infiltration rate were observed between Field O2 and Field O1.

The calculation of the carbon stock showed that Field O3 and Field C1 had a greater carbon stock than Field O2 and both fields are characterized by soil infiltration rates significantly higher than Field O2.

It is well known and illustrated in Chapter (3.1.1) that the infiltration rate is influenced by soil organic matter. However, in the case of the site Trenthorst, it should be mentioned that some additional soil properties are important for high infiltration rates and can compensate for the low soil carbon content. In Field C1, there were very deep and wide soil cracks, which produced preferential flows resulting in high infiltration rates. Field O1 had a higher soil dry bulk density and a lower pore connectivity, caused by a lower fraction of soil pores with a diameter > 50µm (compare Table 3.8), and thus a lower infiltration rate in spite of the higher soil organic carbon content. Field O2 had a lower soil organic carbon content, which resulted in a lower infiltration rate. A good example for the interaction of soil infiltration rate and soil organic carbon was achieved in Field O3 where the higher soil organic carbon content led to a higher soil infiltration rate. However, Field O3 and Field C1 were approximate in the soil organic carbon content but Field C1 had lower pore connectivity, particularly within the tillage boundary (compare Table 3.8).

3.2.2 Dry bulk density

With the exception of Field O1, the soil dry bulk density varied negligibly within the tillage boundary between the conventional and organic fields. The results of dry bulk density are summarized in Table 3.6.

Tab. 3.6: Dry bulk density within tillage boundary influenced by conventional (C) and organic (O) farming systems (site Trenthorst, April 2006)

		Dry bulk density g cm^{-3}	
Farming system		**18-24 cm**	**26-32 cm**
Field C1	Winter wheat	1.46 a	1.48 a
Field O1	Grass	1.53 b	1.59 c
Field O2	Triticale	1.45 a	1.47 a
Field O3	Winter wheat	1.46 a	1.52 b

Mean values followed by the same letters are not significantly different by Duncan's test at the 0.05 level.

The soil dry bulk density in Field O1 was significantly higher in the soil profile deeper than 18 cm compared to the other fields. The measurements of the soil bulk density for the studied fields within the soil profile are illustrated in Figure 3.13.

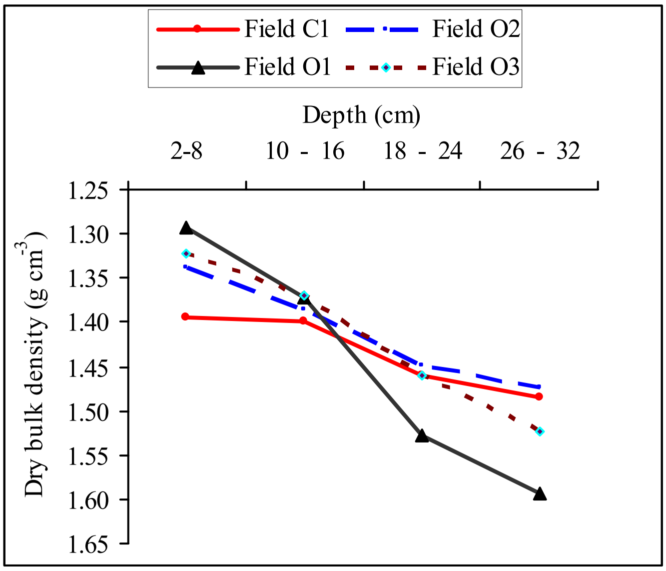


Fig. 3.13: Dry bulk density distribution within the soil profile through several soil depths for conventional (C) and organic (O) farming systems (site Trenthorst, 2006)

The dry bulk density was lower in the topsoil (less than 16 cm) of the organically managed fields compared to the conventionally managed Field C1 (Fig. 3.13). In the deeper soil layer, a considerable increase in the dry bulk density of Field O1 was observed. The soil infiltration rate was influenced by the farming system - soil dry bulk density relationships (Fig. 3.14).

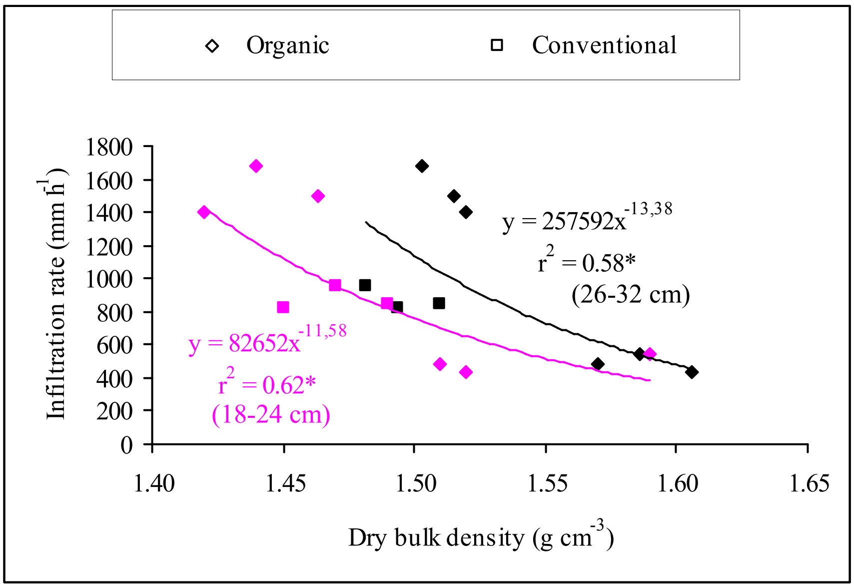


Fig. 3.14: Relationship between soil infiltration rate and soil dry bulk density in conventional and organic-managed fields (site Trenthorst, 2006, sampling depths 18-24 cm and 26-32 cm) (Significance: *= $p < 0.05$, **= $p < 0.01$, ***= $p < 0.001$, ns = not significant)

It can be noted in Figure 3.14 that the relationship between soil infiltration rate and soil dry bulk density at the depth 18-24 cm was found to be similar to that at the depth 26-32 cm. This result indicated that the both soil depths have a similar influence on infiltration rates. The differentiation in the dry bulk density-parallel shift of curves- is plausible and as expected.

3.2.3 Aggregate stability

The soil aggregate stability was influenced only to a minor degree by the investigated farming systems in Trenthorst. Soil textural composition and soil organic carbon (clay-humus-complex) were responsible for a better aggregate stability (compare Tab. 3.6 and Tab.A.2). It was found, in all the studied fields, that the soil aggregate stability was higher in the topsoil compared to the subsoil (Fig. 3.15). This can be traced back to the higher content of soil organic carbon in the topsoil (compare Table A.2).

The aggregate stability in the topsoil of all the organically managed fields was found to be significantly higher compared to the conventionally managed Field C1. In the subsoil, the soil aggregate stability of Field O3 and Field O2 was found to be significantly higher than in Field C1 (Fig. 3.15). However, it seems that the aggregate stability is diminished by conventional farming.

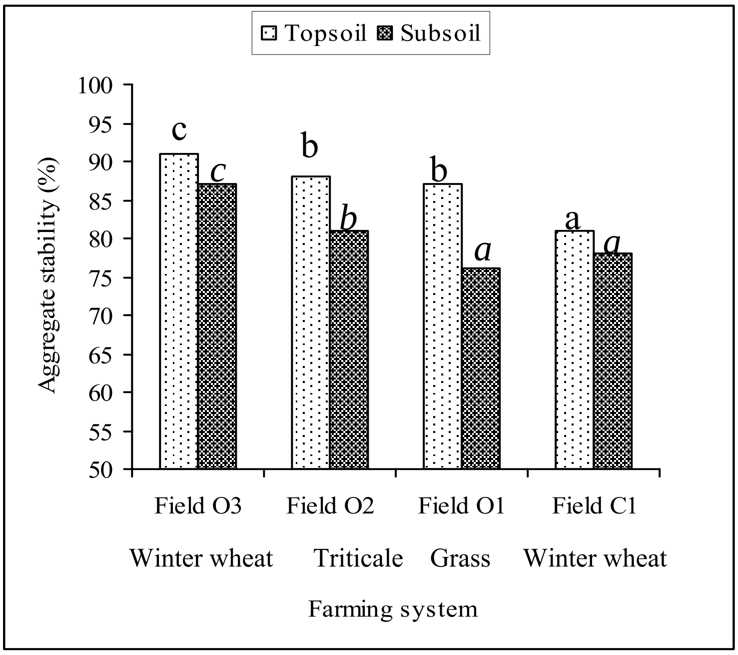


Fig. 3.15: Aggregate stability in topsoil and subsoil of conventional (C) and organic (O) farming systems (site Trenthorst, 2006, sampling depths 0-25 cm and 25-50 cm)

Mean values followed by the same letters are not significantly different by Duncan's test at the 0.05 level.

The relationship between soil infiltration rate and soil aggregate stability is shown in Figure 3.16.

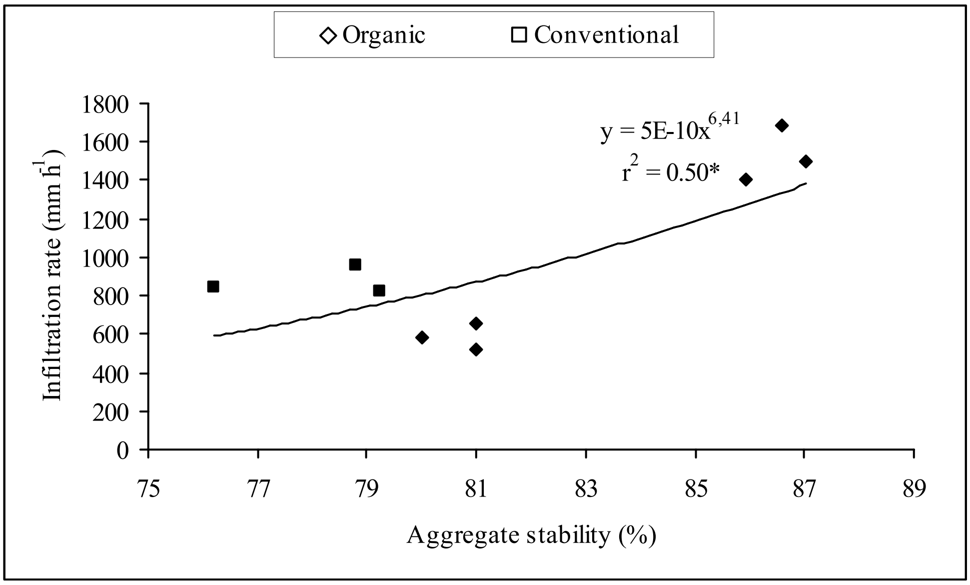


Fig. 3.16: Relationship between soil infiltration rate and soil aggregate stability in conventional and organic-managed fields (site Trenthorst, 2006, sampling depth 25-50 cm) (Significance: *= $p < 0.05$, **= $p < 0.01$, ***= $p < 0.001$, ns = not significant)

The relationship between the aggregate stability and the infiltration rate was less distinct at the Trenthorst site (Fig. 3.16). Despite the higher aggregate stability in the case of organic farming, the infiltration rates were sometimes lower in comparison to conventional farming

3.2.4 Pore size distribution

Pore size distribution of soil varied widely between the investigated farming systems as illustrated in Table 3.7.

Tab. 3.7: Pore size distribution and pore volume of soil through several soil depths for different farming systems (site Trenthorst, 2006)

		Pore size distribution [cm^3 100 cm^{-3}]				Pore volume [cm^3 100 cm^{-3}]	
	Depth	**< 0.2 µm**	**0.2-10 µm**	**10-50 µm**	**>50 µm**		
Field	**(cm)**	**ePD**	**ePD**	**ePD**	**ePD**	**calculated**	**estimated**
Field C1	**2-8**	12.3	12.9	3.83	17.1	46.1	47.6
	10-16	12.8	14.1	3.03	16.1	46.0	47.2
	18-24	12.7	19.4	3.09	8.58	43.7	44.9
	26-32	14.1	20.1	3.10	5.4	42.7	44.2
Field O1	**2-8**	19.2	6.57	9.01	13.0	47.8	51.3
	10-16	16.6	12.4	6.42	10.0	45.5	48.3
	18-24	10.8	14.9	6.27	8.96	40.8	42.3
	26-32	10.7	17.1	5.71	5.15	38.7	40.0
Field O2	**2-8**	9.24	9.2	3.83	26.5	48.7	49.4
	10-16	8.23	12.7	3.81	22.1	46.8	47.6
	18-24	8.70	14.8	5.07	15.9	44.5	45.3
	26-32	8.93	18.7	4.50	11.4	43.5	44.5
Field O3	**2-8**	10.7	10.1	2.93	25.4	49.1	50.2
	10-16	11.5	8.64	3.70	23.5	47.3	48.3
	18-24	12.3	10.8	3.89	16.7	43.7	44.9
	26-32	13.4	13.7	3.68	10.7	41.4	42.6

ePD = equivalent pore diameter

The estimated total pore volume (PV) = [1- (dry bulk density/dry solid density)]*100

According to the results listed in Table 3.7, it was found that soil pores with a diameter >50 µm and 10-50 µm were higher in Field O3 and Field O2 than in Field C1. In Field O1, soil pores with a diameter >50 µm were lower than in the other fields, whereas soil pores with a diameter 10-50 µm were higher than in the other fields. It was noted that soil pores with a diameter 0.2-10 µm were higher in Field C1 compared to the other fields. Whilst soil pores with a diameter < 0.2 µm were higher in Field O1 compared to the other fields.

In all fields, soil pores with a diameter >50 µm decreased with the depth. In contrast, soil pores with a diameter 0.2-10 µm increased with the depth in both farming systems. Soil pores with a diameter <0.2 µm and 10-50 µm decreased by the depth in Field O1, whereas it was quite similar in the upper and lower topsoil of the other fields.

Anyway, soil pores with a diameter >50 µm are considered as the most important soil pores for the water infiltration and roots progress especially at the tillage boundary in the soil. Therefore, it was necessary to focus on the differences between the organic and conventional farming systems occurring in soil pores with a diameter >50 µm (Fig. 3.17)

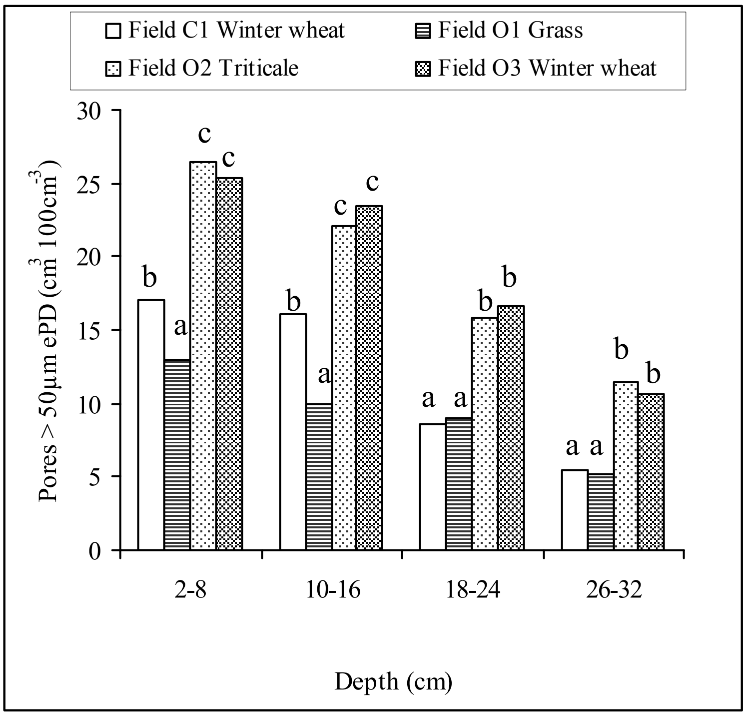


Fig. 3.17: Soil pores with a diameter >50 µm in several soil depths for conventional (C) and organic (O) farming systems (site Trenthorst, 2006)

Mean values followed by the same letters are not significantly different by Duncan's test at the 0.05 level.

Figure 3.17 shows that in all depths, soil pores with a diameter >50 µm were significantly higher in Field O3 and Field O2 compared to Field C1 and Field O1. As already mentioned, soil pores with a diameter >50 µm decreased with increasing the soil depth (Fig. 3.17).

The calculated and estimated pore volume showed a very good agreement (Tab. 3.7).

3.2.5 *Soil water retention*

The results summarized in Figure 3.18 illustrate that there were differences in soil water retention between the investigated farming systems.

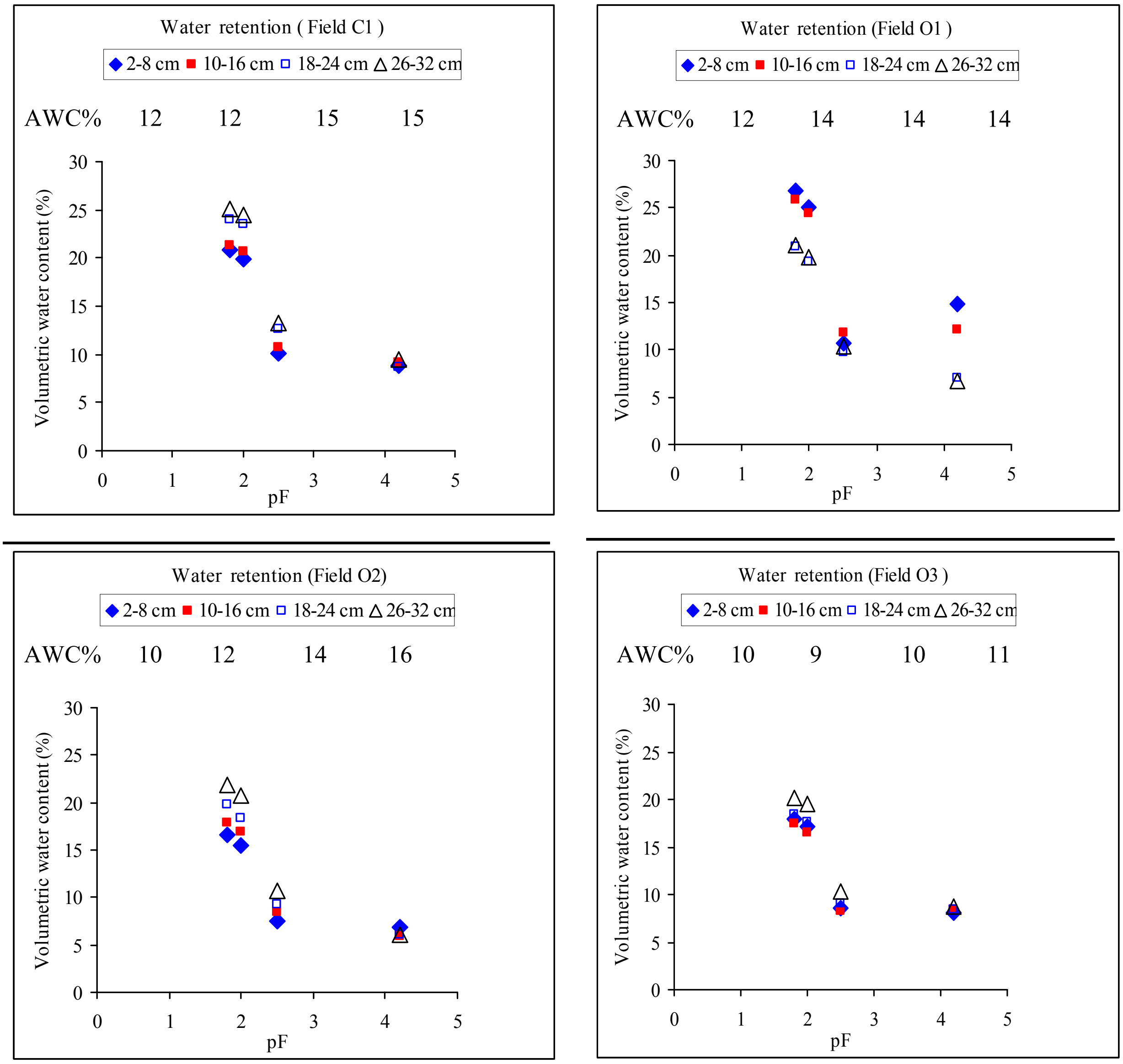


Fig. 3.18: Soil water retention and available water holding capacity (AWC) for conventional (C) and organic (O) farming systems (site Trenthorst, 2006)

Figure 3.18 shows that the soil water retention at pF values 1.8 , 2 and 2.5 in the upper topsoil (2-8 cm, 10-16 cm) was higher in Field O1 compared to the other fields whereas in the lower topsoil (18-24 cm, 26-32 cm), Field C1 had higher soil water retention than the other fields. At pF value 4.2 in the upper topsoil, the water retention was found to be higher in Field O1 compared to the other fields. However, in the lower topsoil, Field O3 had water retention similar to that in Field C1 and higher than the other fields. These results were due to a higher portion of micropores (soil pores with a diameter < 0.2 µm) in the upper topsoil of Field O1 compared to the other fields. Also due to a higher portion of micropores in the lower topsoil of Field O3 and Field C1 compared to the other fields (compare Table 3.8). It was observed that at all pF values, the water retention in Field O1 decreased by the depth and it was greater in the upper topsoil than in the lower topsoil whereas in the other fields, the soil water retention increased by the depth and it was greater in the lower topsoil compared to the upper topsoil. Estimation of the available water holding capacity (AWC) of the investigated fields revealed that no considerable differences have been observed between Field O1, Field O2 and Field C1 in the available water holding capacity, either in the upper topsoil or in the lower topsoil. In addition, all of those fields had a higher available water holding capacity than Field O3. This result can be attributed to a lower portion of mesopores (soil pores with a diameter 0.2-10 µm) in Field O3 compared to the other fields (compare Table 3.8).

3.2.6 Dehydrogenase activity

The soil biological analysis showed a variation in the dehydrogenase activity between the studied farming systems (Fig. 3.19).

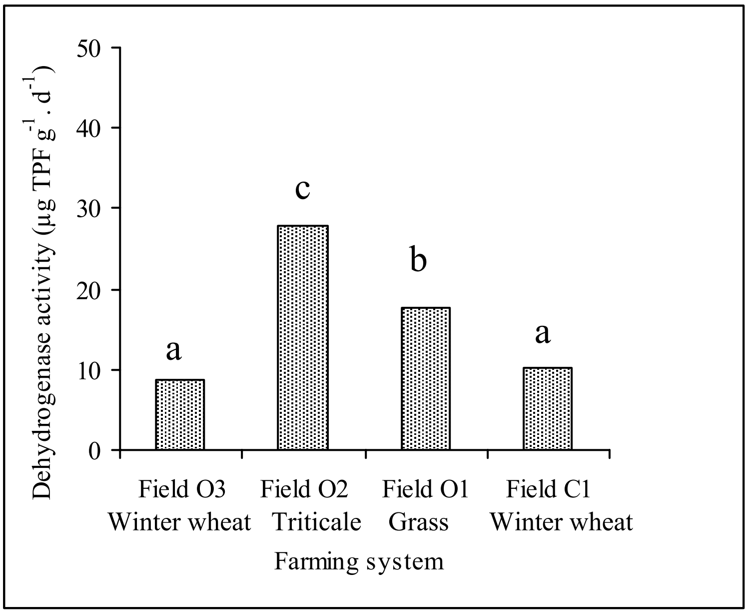


Fig. 3.19: Dehydrogenase activity of soil for conventional (C) and organic (O) farming systems (site Trenthorst, 2006, sampling depth 0-30 cm)
Mean values followed by the same letters are not significantly different by Duncan's test at the 0.05 level.

The results reveal that the dehydrogenase activity in Field O2 and Field O1 was significantly higher than in Field C1 and Field O3 (Fig. 3.19).

3.2.7 Earthworms

The earthworm abundance in the organic farming system was found to be different in comparison to the conventional farming system (Fig. 3.20).

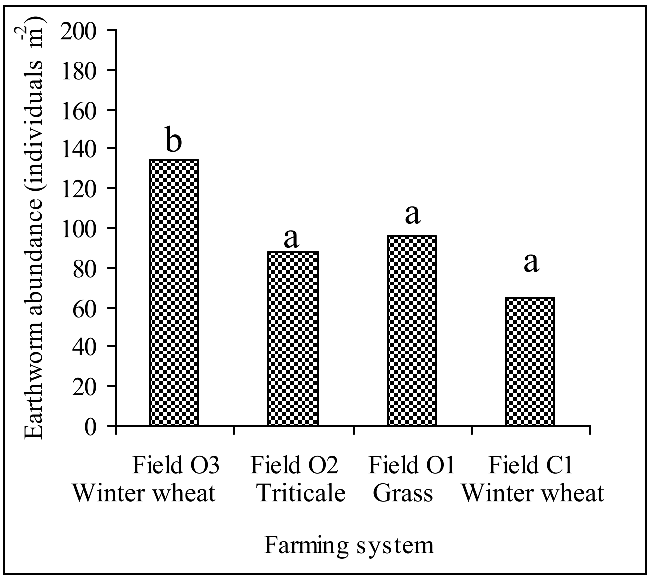


Fig. 3.20: Earthworm abundance in the soil for conventional (C) and organic (O) farming systems (site Trenthorst, 2006)

Mean values followed by the same letters are not significantly different by Duncan's test at the 0.05 level.

The earthworm abundance in Field O3 was found to be significantly higher compared to the other investigated fields. No significant differences in earthworm abundance were found between Field O1, Field O2 and Field C1. In any case, it can be stated that the population of earthworms is impaired by the conventional farming system, because the lowest earthworm abundance was estimated in Field C1.

That applies also to the earthworm biomass, which was found to be significantly higher in the organically managed fields (approximately 2-4 times more) than in the conventionally managed Field C1. The greatest earthworm biomass was observed in Field O1 (Fig. 3.21).

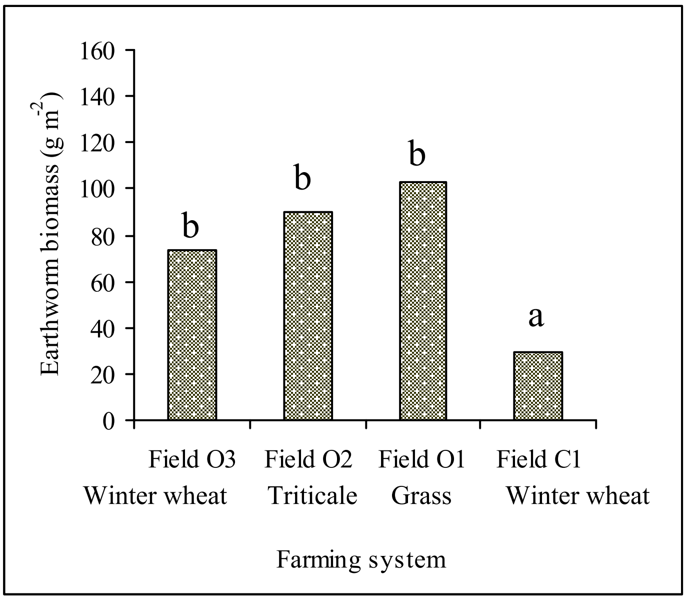


Fig. 3.21: Earthworm biomass in the soil for conventional (C) and organic (O) farming systems (site Trenthorst, 2006)

Mean values followed by the same letters are not significantly different by Duncan's test at the 0.05 level.

The age structure and the ecological groups of the earthworm population were influenced by the different farming systems (Table 3.8).

Tab. 3.8: Age structure and ecological groups of the earthworm populations for conventional (C) and organic (O) farming systems (site Trenthorst, 2006)

Farming system	**Age structure**		**Ecological groups**		
	Juvenile	**Adult**	**Epigeic**	**Endogeic**	**Anecic**
			Individuals m^{-2}		
Field O3	77 b	57 b	16 b	97 b	21 ab
Field O2	45 a	43 b	8 ab	58 a	22 ab
Field O1	64 ab	32 ab	6 a	50 a	40 b
Field C1	48 a	17 a	17 b	30 a	18 a

Mean values followed by the same letters are not significantly different by Duncan's test at the 0.05 level.

The results in Table 3.8 reveal that the number of juvenile individuals in Field O3 and the number of adult individuals in Field O3 and Field O2 were significantly higher than in Field C1. The number of epigeic individuals in Field C1 was significantly higher than in Field O2 and Field O1, but it was not significantly different from in Field O3. The number of endogeic individuals in Field O3 was found to be significantly higher compared to the other fields. The number of anecic individuals in Field O1 was significantly higher than in Field C1. In both investigated farming systems, the number of endogeic individuals was found to be higher than the number of anecic and epigeic individuals. The relationship between soil infiltration rate and earthworm abundance, as well as the relationship between soil infiltration rate and earthworm biomass are illustrated in Figures 3.22 and 3.23.

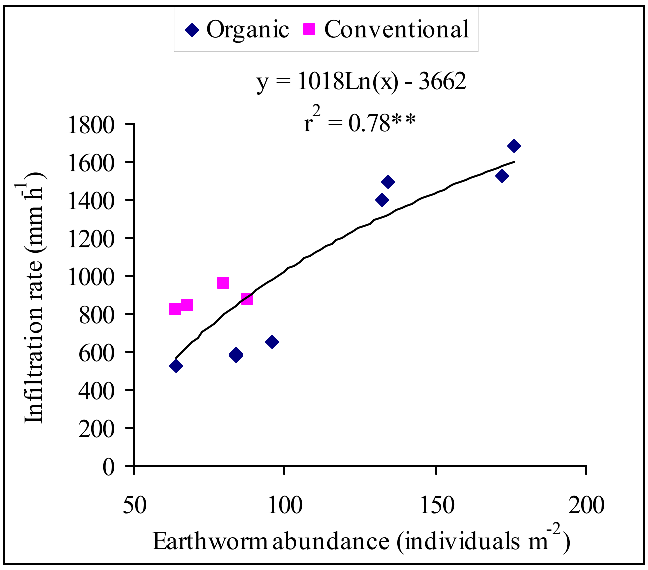


Fig. 3.22: Relationship between soil infiltration rate and earthworm abundance in conventional and organic-managed fields (site Trenthorst, 2006) (Significance: *= $p < 0.05$, **= $p < 0.01$, ***= $p < 0.001$, ns = not significant)

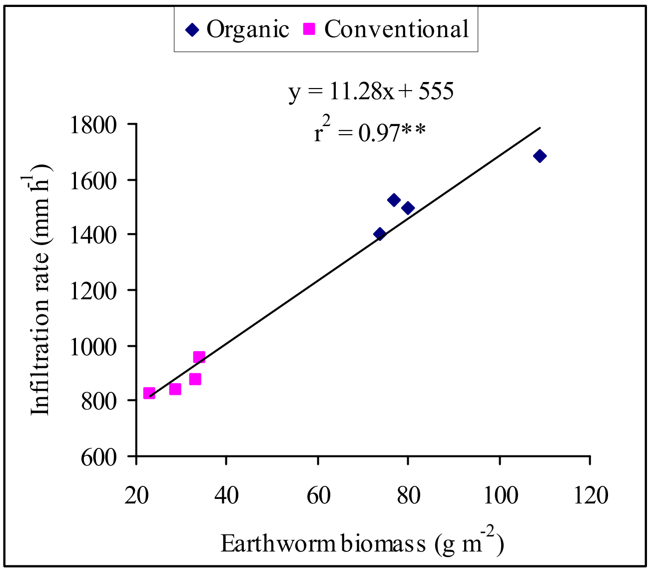


Fig. 3.23: Relationship between soil infiltration rate and earthworm biomass in conventional and organic-managed fields (site Trenthorst, 2006) (Significance: *= $p < 0.05$, **= $p < 0.01$, ***= $p < 0.001$, ns = not significant)

Figures 3.22 and 3.23 show that the infiltration rate was significantly influenced by the earthworm abundance and biomass. It may be deduced that the high earthworm activity is an indication for enhanced infiltration rates in soils. It can be noted that the relationship between earthworm biomass and the infiltration rate was stronger in comparison to earthworm abundance.

3.2.8 *Soil chemical properties*

The soil nutrient content was influenced to a great extent by the different farming systems (Table 3.9).

Tab. 3.9: Soil nutrient content of conventional (C) and organic (O) farming systems (site Trenthorst, 2006, sampling depth 0-8 cm)

Farming system	**Crop**	**C**	**N**	**pH**	**P**	**K**	**Mg**
		%	**%**		**mg kg^{-1}**	**mg kg^{-1}**	**mg kg^{-1}**
Field O3	**Winter wheat**	1.35	0.113	6.6	82	98	129
Field O2	**Triticale**	1.06	0.099	6.3	65	130	91
Field O1	**Grass**	4.54	0.206	5.5	238	299	311
Field C1	**Winter wheat**	1.61	0.093	6.5	35	133	133

The results have shown that the soil N, Mg, K and organic carbon content in Field O1 were considerably greater than in the other fields. The soil P content in Field O3, Field O2 and Field O1 was considerably greater than in Field C1. As expected, the soil pH in Field O1 was lower than in the other fields. Whereas, no significant difference in the soil pH was observed between Field O3 and Field C1. The following ranking order for soil pH can be summarized: Field C1, Field O3 > Field O2 > Field O1.

3.3 Infiltration capacity, soil properties and earthworm population in relation to soil tillage

The long-term field experiment, Field No. 4 in Braunschweig, and the practice related Field No. 1 in Mariensee, have been investigated under different soil tillage intensities. Field No. 4 was sown with field beans and included the treatments Conservation Tillage (Plot 1.3) and Conventional Tillage (Plot 2.3). Field No. 1 was sown with winter wheat and included the treatments Shallow Tillage (Plot S) and Deep Tillage (Plot D). The soil texture of the investigated fields is summarized in Table 3.10.

Tab. 3.10: Soil texture analysis of fields in Braunschweig (2006) and Mariensee (2007)

	Braunschweig Field No. 4		**Mariensee Field No. 1**	
Soil textural classes	Conservation tillage	Conventional tillage	Shallow tillage	Deep tillage
0-30 cm				
Sand (%)	34	35	29	28
Silt (%)	59	58	48	49
Clay (%)	7	7	23	23
30-60 cm				
Sand (%)	51	55	29	34
Silt (%)	43	40	49	45
Clay (%)	6	5	22	21

According to the results listed in Table 3.11, in Braunschweig it can be assumed that the soil textural classes of the plot treated with conservation tillage and the plot treated with conventional tillage were nearly the same. The soil is characterized by a sand content above 30 % (topsoil) and above 50 % (subsoil), whereas the silt content was higher in the topsoil (nearly 60 %) and lower in the subsoil (40 %). As expected, the clay was low in the top and subsoil.

In contrast to Braunschweig, the soil of the plot treated with shallow tillage and the plot treated with deep tillage in Mariensee was clearly more cohesive with a clay content of above 20 %. The sand content ranged between 30-35 % and the silt between 45-50 %.

The soil type of the investigated fields in Braunschweig and Mariensee can be characterized according to the German soil classification system (KA 5) as follows:

	Topsoil		**Subsoil**	
Conservation, Conventional	sandy silt	(Us)	strong silty sand	(Su 4)
Shallow, Deep	weak sandy loam	(Ls 2)	weak sandy loam	(Ls 2)

3.3.1 *Soil infiltration rate*

The soil infiltration rate was influenced by soil tillage and site properties to a great extent as shown in Figure 3.24.

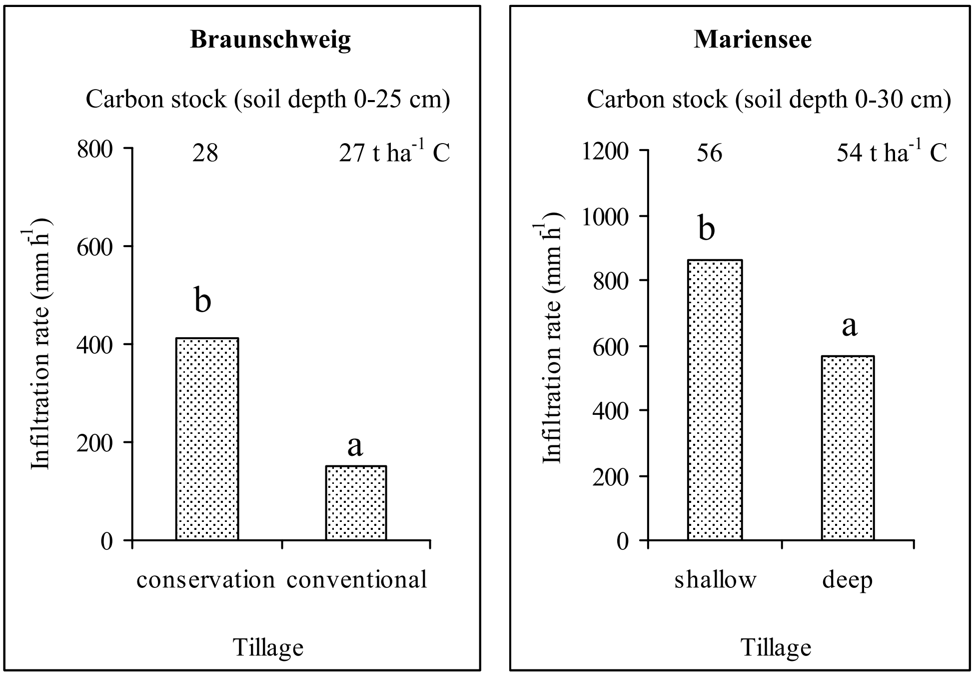


Fig. 3.24: Soil infiltration rate and carbon stock for different soil tillage intensities (site Braunschweig, infiltration measurement in October 2006, crop: field beans; site Mariensee, infiltration measurement in October 2007, crop: winter wheat)
Mean values followed by the same letters are not significantly different by Duncan’s test at the 0.05 level.

Figure 3.24 shows that the infiltration rate was substantially affected by different intensities of soil tillage. In Braunschweig, the soil infiltration rates were significantly higher in the plots with conservation tillage than in the plots with conventional tillage. In Mariensee, it was noted that the plots under shallow tillage had soil infiltration rates significantly higher compared to the plots under deep tillage. The soil infiltration rates in Mariensee were found to be considerably higher compared to Braunschweig. That was due to the influence of different site properties. The infiltration rate was found to be considerably impacted by the soil carbon stock, which had a significant effect in increasing the infiltration rates in the soil.

3.3.2 Dry bulk density and soil penetration resistance

The investigations of Field No. 4 in Braunschweig revealed differences in the soil dry bulk density between conservation tillage and conventional tillage (Fig. 3.25).

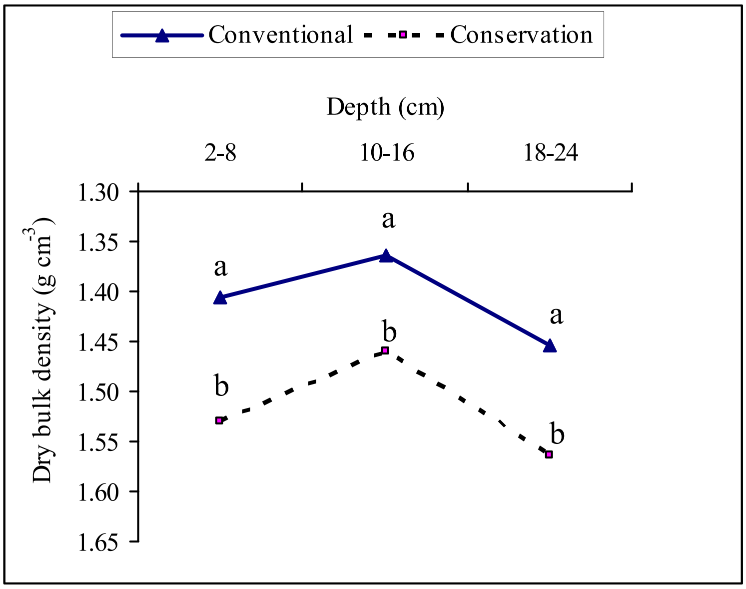


Fig. 3.25: Dry bulk density of topsoil as affected by soil tillage intensities (site Braunschweig, 2006)
Mean values followed by the same letters are not significantly different by Duncan's test at the 0.05 level.

The soil dry bulk density under conventional tillage was significantly lower at all depths compared to the bulk density under conservation tillage (Fig. 3.25).

Soil penetration resistance, another indicator to quantify soil structural changes, showed only small differences in the case of shallow or deep tillage in Mariensee (Fig. 3.26).

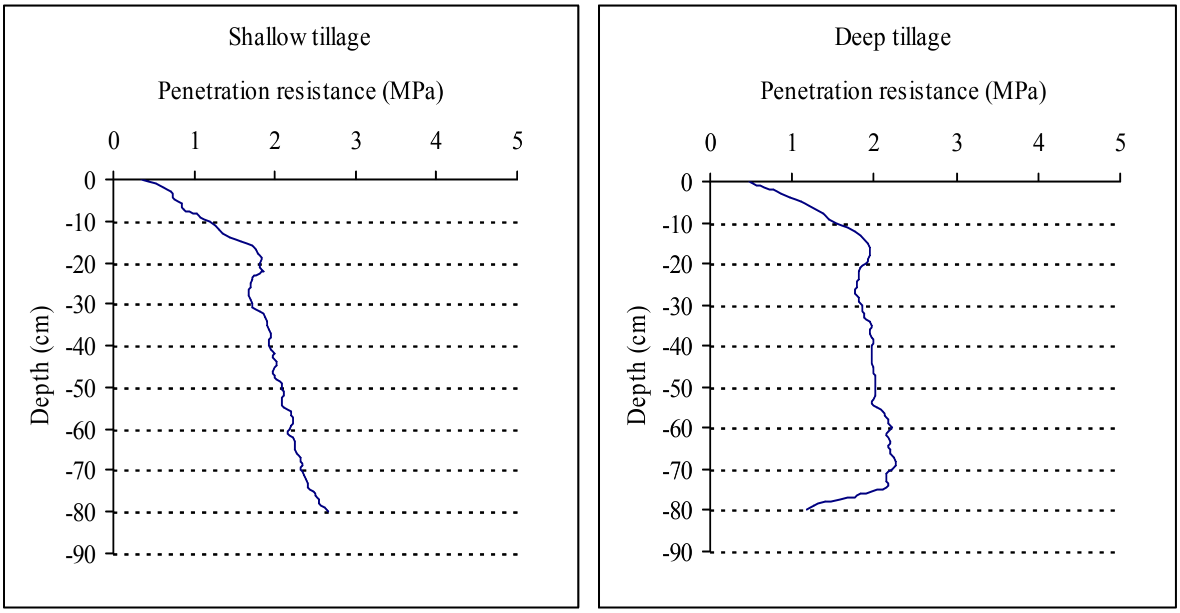


Fig. 3.26: Soil penetration resistance for different intensities of soil tillage (site Mariensee, 2007)

It can be seen in Figure 3.26 that in the topsoil (0-20 cm), the soil penetration resistance increased sharply with the depth, and seemed nearly the same under both shallow and deep tillage. Whereas, under deep tillage in the subsoil, the soil penetration resistance remained about the same until a depth of 70 cm and then decreased strongly up to the depth 80 cm. This was probably caused by a mole. In the subsoil under shallow tillage, the soil penetration resistance was moderately increasing starting from a depth of 30 cm up to 80 cm.

3.3.3 Aggregate stability

The different tillage systems and intensities have influenced the soil aggregate stability to different degrees, slightly in Braunschweig and strongly in Mariensee (Fig. 3.27). In Braunschweig, the soil aggregate stability of the topsoil was significantly higher in the plots under conservation tillage than in the plots under conventional tillage. Whereas in the subsoil, no significant differences in the aggregate stability were observed between conservation and conventional tillage. In Mariensee, it was found that the plots had significantly a higher soil aggregate stability in the top and subsoil under shallow tillage compared to the plots under deep tillage.

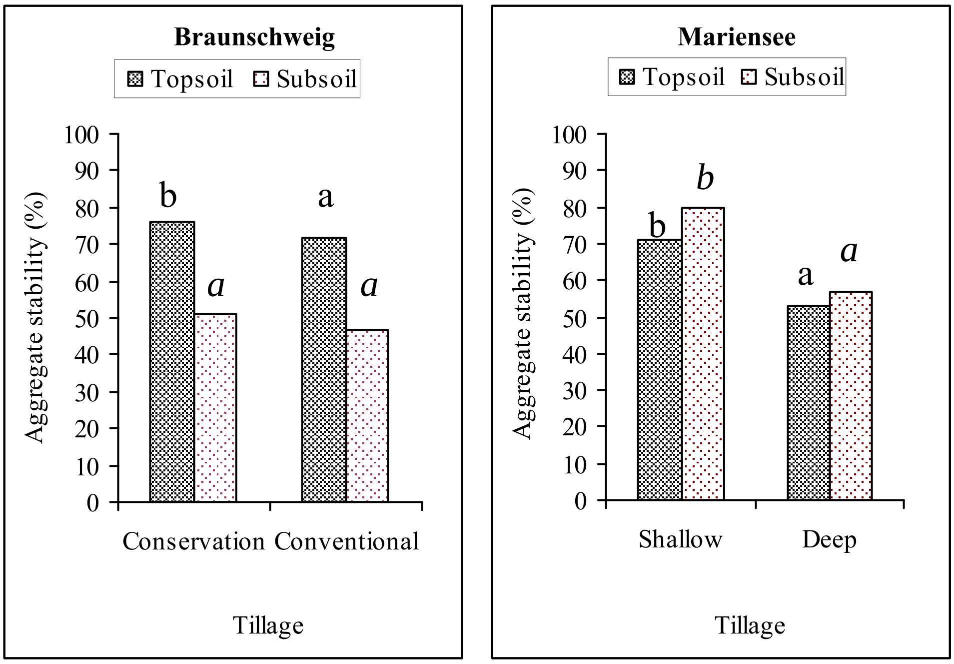


Fig. 3.27: Soil aggregate stability in topsoil (0-25 cm) and subsoil (25-50 cm) as affected by soil tillage intensities (site Braunschweig, 2006; crop: field beans; site Mariensee, 2007, crop: winter wheat).
Mean values followed by the same letters are not significantly different by Duncan's test at the 0.05 level.

In Braunschweig, the soil aggregate stability of the topsoil was found to be higher compared to the subsoil. This can be attributed to the greater content of organic matter in the topsoil compared to the subsoil (compare Tab. A.2). In Mariensee, it was noted that the soil aggregate stability was lower in the topsoil than in the subsoil (Fig. 3.27). Reduced tillage intensity increased the stability of soil aggregates and led in this way to higher infiltration rates.

The relationship between soil infiltration rate and soil aggregate stability is given in Figure 3.28.

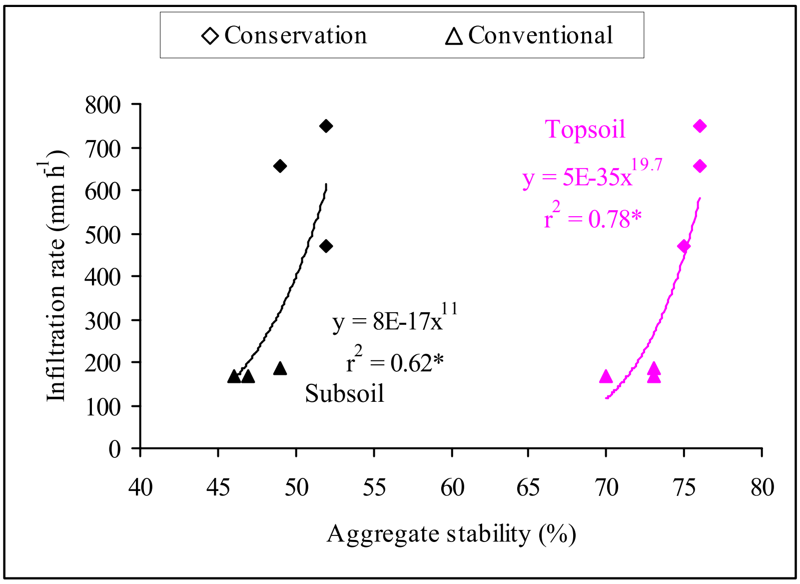


Fig. 3.28: Relationship between soil infiltration rate and soil aggregate stability as affected by soil tillage intensities (site Braunschweig, 2006; sampling depths 0-25 cm and 25-50 cm) (Significance: *= $p < 0.05$, **= $p < 0.01$, ***= $p < 0.001$, ns = not significant)

Figure 3.28 reveals that the soil aggregate stability influenced the soil infiltration rate significantly in both tillage treatments in the top and subsoil. The relationship between soil infiltration rate and soil aggregate stability was stronger in the topsoil than in the subsoil.

3.3.4 Dehydrogenase activity

The soil biological investigations revealed that the dehydrogenase activity was noticeably affected by different soil tillage intensities (Fig. 3.29).

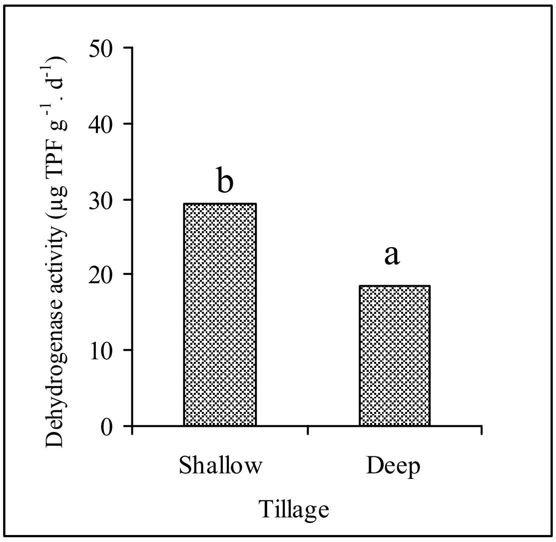


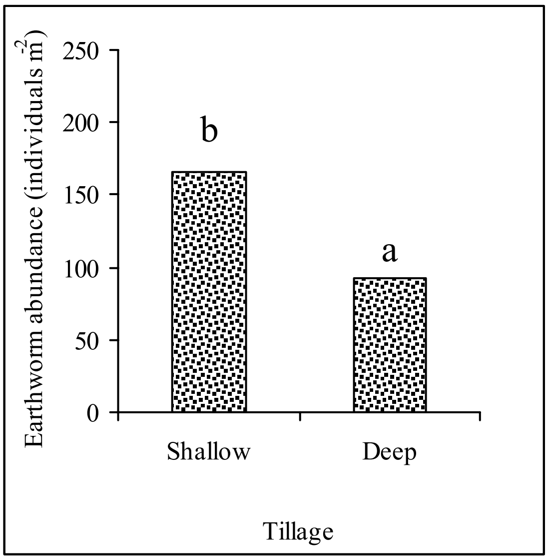
Fig. 3.29: Dehydrogenase activity of soil as affected by soil tillage intensities (site Mariensee, 2007, crop: winter wheat, sampling depth 0-30 cm)

Mean values followed by the same letters are not significantly different by Duncan's test at the 0.05 level.

The dehydrogenase activity was significantly higher in the plots under shallow tillage compared to the plots under deep tillage (Fig. 3.29). That was because the dehydrogenase activity, as known, is positively correlated with the soil moisture. Besides, shallow tillage leads to a higher earthworm activity, a higher aggregate stability and then to a higher water infiltration rate, resulting in a higher content of soil moisture, causing a higher dehydrogenase activity in the soil than deep tillage.

3.3.5 Earthworms

Earthworm abundance and biomass were obviously influenced by different soil tillage intensities (Fig. 3.30)



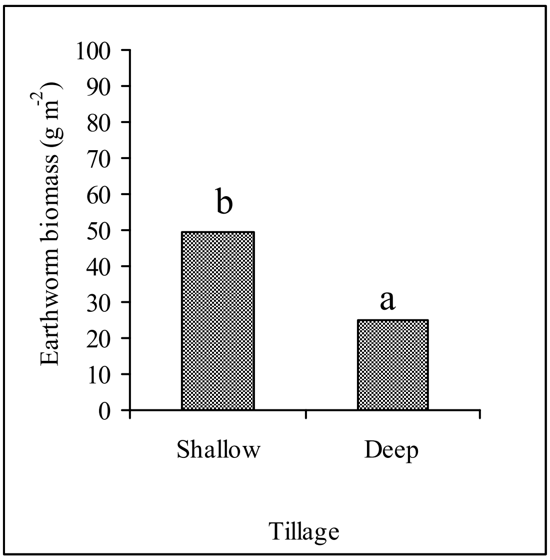


Fig. 3.30: Earthworm abundance and biomass as affected by different soil tillage intensities (site Mariensee, 2007, crop: winter wheat)

Mean values followed by the same letters are not significantly different by Duncan's test at the 0.05 level.

Earthworm abundance and biomass were significantly greater in the plots under shallow tillage compared to the plots under deep tillage (Fig. 3.30). This result is attributed to the fact that deep tillage causes a considerable damage to earthworms leading to a decrease in the earthworm population.

Moreover, the age structure and the ecological groups of the earthworm population varied under different soil tillage intensities (Table 3.11).

Tab. 3.11: Age structure and ecological groups of earthworm population as affected by different soil tillage intensities (site Mariensee, 2007)

Tillage intensity	**Age structure**		**Ecological groups**		
	Juvenile	**Adult**	**Epigeic**	**Endogeic**	**Anecic**
			Individuals m^{-2}		
Shallow	130 a	36 b	43 a	111 b	12 a
Deep	73 a	19 a	20 a	68 a	4 a

Mean values followed by the same letters are not significantly different by Duncan's test at the 0.05 level.

The results showed that the numbers of endogeic individuals as well as the number of adult individuals were significantly higher in the shallow-tilled plots compared to the deep-tilled plots. No significant differences were observed in the numbers of juvenile worms as well as epigeic and anecic individuals between shallow and deep tillage. These results support the fact that shallow tillage can conserve earthworm populations and sustain them to a large degree as compared to deep tillage. The relationship between soil infiltration rate and earthworm abundance, as well as the relationship between soil infiltration rate and earthworm biomass are shown in Figures 3.31 and 3.32.

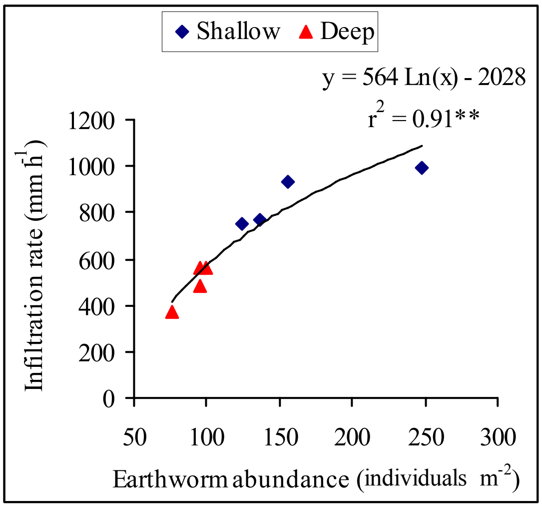


Fig. 3.31: Relationship between soil infiltration rate and earthworm abundance as affected by different soil tillage intensities (site Mariensee, 2007)
(Significance: *= $p < 0.05$, **= $p < 0.01$, ***= $p < 0.001$, ns = not significant)

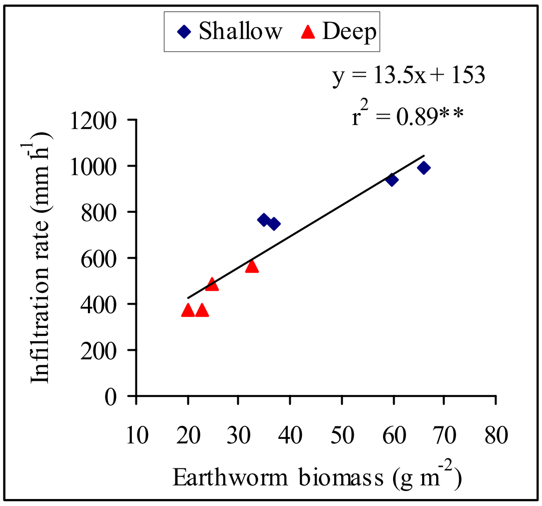


Fig. 3.32: Relationship between soil infiltration rate and earthworm biomass as affected by different soil tillage intensities (site Mariensee, 2007)
(Significance: *= $p < 0.05$, **= $p < 0.01$, ***= $p < 0.001$, ns = not significant)

Figures 3.31 and 3.32 demonstrate that the soil infiltration rate was significantly affected by earthworm abundance and biomass in the soil. The enhanced infiltration rates can be occurred expectedly in the soils, which have a high earthworm activity.

3.3.6 Soil chemical properties

Soil chemical properties were estimated for conservation and conventional tillage in Braunschweig and for shallow and deep tillage in Mariensee. The soil nutrient content of the upper seedbed zone was considerably affected by different soil tillage intensities (Table 3.12). This soil depth may be of high importance for an adequate infiltration rate.

Tab. 3.12: Soil nutrient content of plots with different soil tillage intensities (site Braunschweig, 2006; site Mariensee, 2007, sampling depth 0-8 cm)

Tillage system	**Crop**	**C**	**N**	**pH**	**P**	**K**	**Mg**
		%	**%**		**mg kg^{-1}**	**mg kg^{-1}**	**mg kg^{-1}**
Conservation	**(Field bean)**	1.34	0.096	5.3	54	150	66
Conventional	**(Field bean)**	1.26	0.080	5.3	31	88	50
Shallow	**(Winter wheat)**	1.27	0.125	6.5	44	133	95
Deep	**(Winter wheat)**	1.31	0.130	6.1	30	107	115

The results of the Braunschweig site shown in Table 3.12 reveal that the soil organic carbon, N, P, K, and Mg content were higher in the conservation-tilled plots compared to the conventionally tilled plots. No difference in the soil pH was observed between conservation and conventional tillage. The pH values were low. In Mariensee, the soil P, and K content were higher in the shallow-tilled plots compared to the deep-tilled plots. In contrast, the soil Mg content was higher in deep tillage than shallow tillage. No considerable differences were detected in the soil N and organic carbon content, nor in the soil pH between shallow and deep tillage.

3.4 Infiltration capacity, soil properties and earthworm population in relation to fertilization

Three plots of the long-term field experiment (Field No. 36) have been investigated in Braunschweig to estimate the effect of different fertilization treatments on the infiltration rate and further soil properties. The investigated rapeseed plots comprised the only mineral-fertilized Plot No. 4 (NPK), the organic-fertilized Plot No. 10 (fym) and the combined-fertilized Plot No. 12 (NPK+fym).

The results of soil texture analysis for the investigated plots are shown in Table 3.13. These data sets are basically required for the assessment of the infiltration capacity and selected soil properties including the earthworm population as affected by different fertilization treatments.

Tab. 3.13: Soil texture analysis of different fertilized plots (site Braunschweig, Field No. 36, 2006)

Soil textural classes	NPK	fym	NPK+fym
0-30 cm			
Sand (%)	36	37	37
Silt (%)	57	55	55
Clay (%)	7	8	8
30-60 cm			
Sand (%)	50	41	52
Silt (%)	44	52	42
Clay (%)	6	7	6

fym = farmyard manure

According to the results shown in Table 3.13, the texture of the topsoil was nearly similar in all the studied plots. In the subsoil, the mineral-fertilized plot (NPK) and the combined-fertilized plot (NPK+fym) had approximately similar soil texture, both had a higher sand content and a lower silt content compared to the organic-fertilized plot (fym). The studied plots are characterized by a sand content in the range between 30-50 %, a silt content estimated between 40-60 % and a clay content less than 10 %. The soil type of the investigated plots can be characterized according to the German soil classification system (KA 5) as follows:

	Topsoil		Subsoil	
NPK	sandy silt	(Us)	strong silty sand	(Su 4)
Fym	sandy silt	(Us)	sandy silt	(Us)
NPK+fym	sandy silt	(Us)	strong silty sand	(Su 4)

3.4.1 Soil infiltration rate

The soil infiltration rate was strongly influenced by the different fertilization treatments (Fig. 3.33).

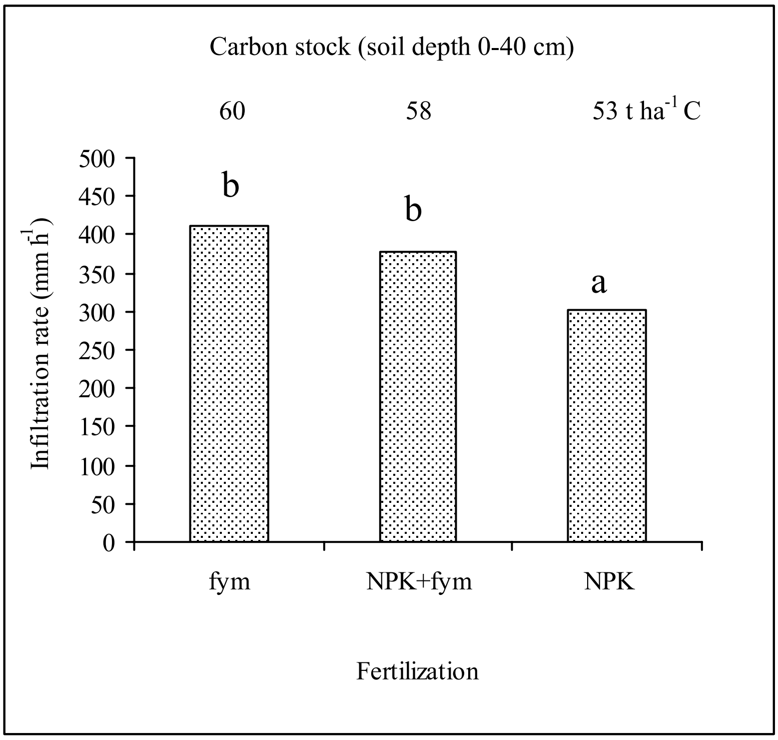


Fig. 3.33: Soil infiltration rate and carbon stock as affected by different fertilization treatments (site Braunschweig, Field No. 36, crop: rapeseed, infiltration measurement in November 2006)
Mean values followed by the same letters are not significantly different by Duncan's test at the 0.05 level.

Figure 3.33 shows that no significant differences in the soil infiltration rate were noticed between the organic-fertilized plot (fym) and the combined-fertilized plot (NPK+fym) and both had an infiltration rate significantly higher compared to the mineral-fertilized plot (NPK). Based on this result, it was basically required to identify the extreme differences between the mineral and organic fertilization in their effects on the infiltration capacity and further soil properties comprising the earthworm populations. It can be observed that the organic fertilization increased the soil infiltration rate by nearly 25% compared to the mineral fertilization. The infiltration rate was concretely associated with the soil carbon stock, which had a significant role in sustaining high infiltration rates in the soil (Fig. 3.34).

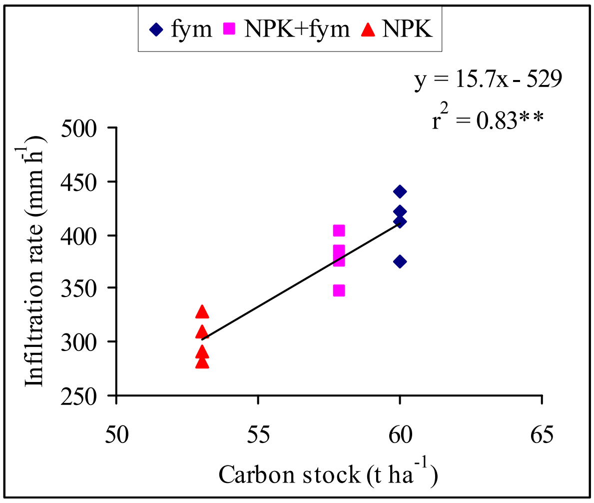


Fig. 3.34: Relationship between soil infiltration rate and soil carbon stock as affected by different fertilization treatments (site Braunschweig, Field No. 36, 2006, sampling depth of carbon 0-40 cm) (Significance: *= $p < 0.05$, **= $p < 0.01$, ***= $p < 0.001$, ns = not significant)

3.4.2 Dry bulk density and soil penetration resistance

The undisturbed soil samples in ring tubes of the long-term field experiment (Field No. 36) in Braunschweig have shown differences in the soil dry bulk density between the plots with different fertilization (Fig. 3.35).

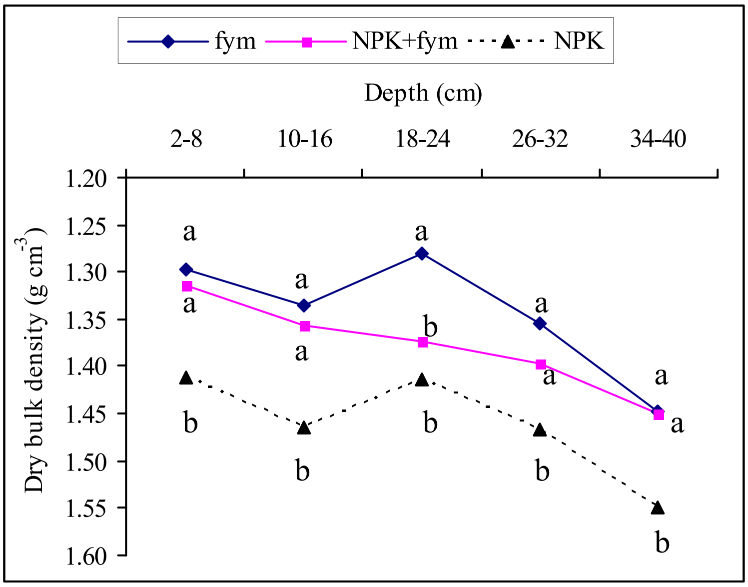


Fig. 3.35: Dry bulk density for different soil depths as affected by different fertilization treatments (site Braunschweig, Field No. 36, 2006)

Mean values followed by the same letters are not significantly different by Duncan's test at the 0.05 level.

The soil dry bulk density of the organic-fertilized plot (fym) and the combined-fertilized plot (NPK+fym) was significantly lower compared to the mineral-fertilized plot (NPK). That was a consequence of the higher soil organic carbon content in the organic-fertilized plot.

It can be deduced that the organic fertilization can partly reduce the soil bulk density by more than 0.1 g cm^{-3} in comparison to the mineral fertilization.

The relationship between soil infiltration rate and soil dry bulk density is demonstrated in Figure 3.36.

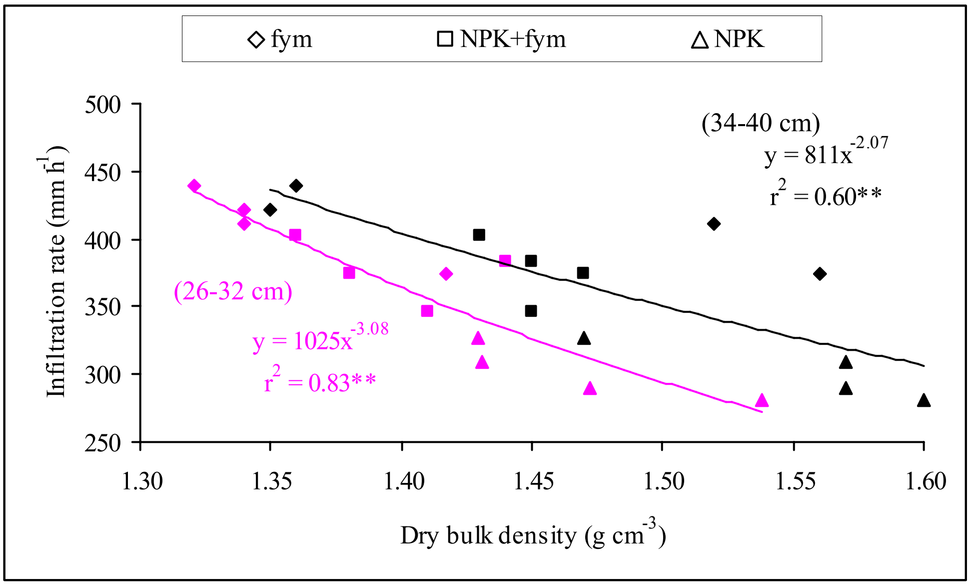
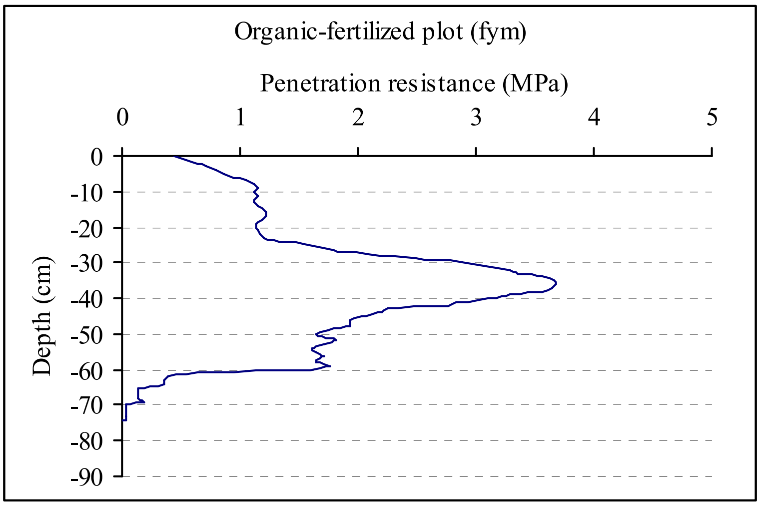


Fig. 3.36: Relationship between soil infiltration rate and soil dry bulk density depending on soil depth and fertilization management (site Braunschweig, 2006, Field No. 36)
(Significance: *= $p < 0.05$, **= $p < 0.01$, ***= $p < 0.001$, ns = not significant)

Figure 3.36 shows that the soil infiltration rate was significantly associated with the soil dry bulk density and fertilization management. The relationship between the soil infiltration rate and the soil dry bulk density at a depth of 26-32 cm was stronger in comparison to the depth 34-40 cm. This result stated that the dry bulk density in the lower topsoil has a greater influence on the soil infiltration potential under different fertilization treatments compared to the upper subsoil.

A strong relationship exists between the soil bulk density and the soil penetration resistance, which is more susceptible and higher in resolution over soil depth.

The measurements of soil penetration resistance in the long-term field experiment (Field No. 36) showed distinct differences between the different fertilization treatments – lower values in the plot with organic fertilization (Fig. 3.37). The reason is attributed to a lower bulk density and a better soil structure.



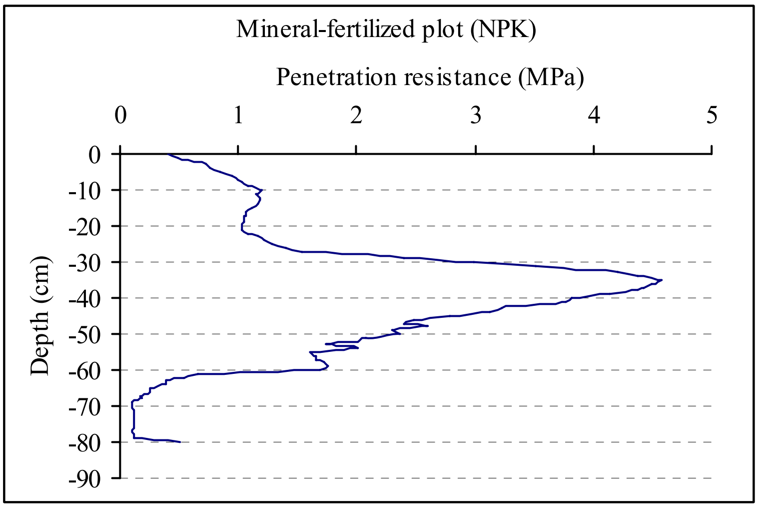


Fig. 3.37: Soil penetration resistance depending on fertilization management (site Braunschweig, Field No. 36, 2006)

The soil profiles are characterized by distinct soil compaction zones (more pronounced in the mineral-fertilized plot (NPK)) between 35 – 45 cm soil depth followed by subsoil with lower penetration resistance.

The causal chain soil organic matter → dry bulk density → penetration resistance affect the infiltration potential of soils:

Soil organic matter	+	-
Dry bulk density	-	+
Penetration resistance	-	+
Infiltration	+	-

3.4.3 Aggregate stability

The different fertilizer applications have induced considerable differences in the soil aggregate stability (Fig. 3.38). It was found that the soil aggregate stability of the topsoil (0-25 cm) and subsoil (25-50 cm) was significantly higher in the combined-fertilized plot (NPK+fym) and the organic-fertilized plot (fym) compared to the mineral-fertilized plot (NPK). No significant differences in the aggregate stability were observed between the combined-fertilized plot (NPK+fym) and the organic-fertilized plot (fym). It can be noted that the organic fertilization led to a higher soil aggregate stability (+15 %) compared to the mineral fertilization.

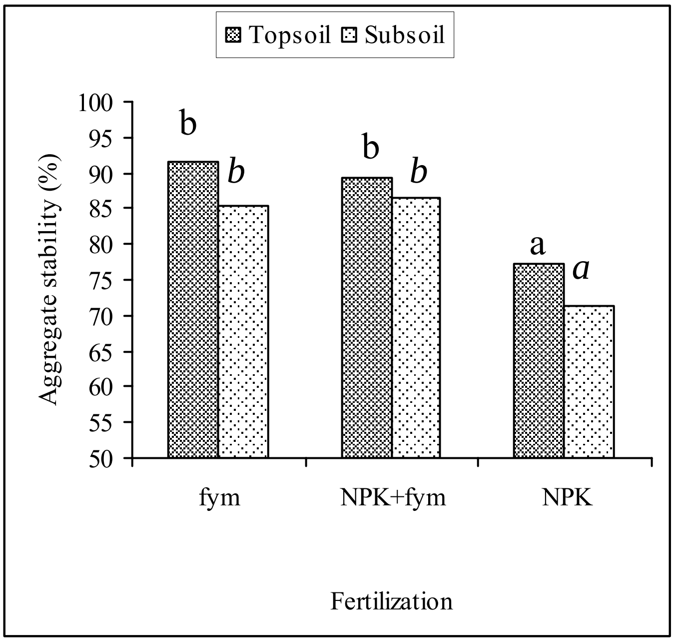


Fig. 3.38: Soil aggregate stability in topsoil (0-25 cm) and subsoil (25-50 cm) as affected by different fertilization treatments (site Braunschweig, Field No. 36, 2006, crop: rapeseed)
Mean values followed by the same letters are not significantly different by Duncan's test at the 0.05 level.

In all the investigated plots, the aggregate stability of the topsoil was found to be higher compared to the subsoil (Fig. 3.38). This result was due to the higher content of organic matter in the topsoil compared to the subsoil (compare Tab. A.2).

The aggregate stability of soil significantly influenced the infiltration rate. The relationship between soil infiltration rate and soil aggregate stability is given in Figure 3.39.

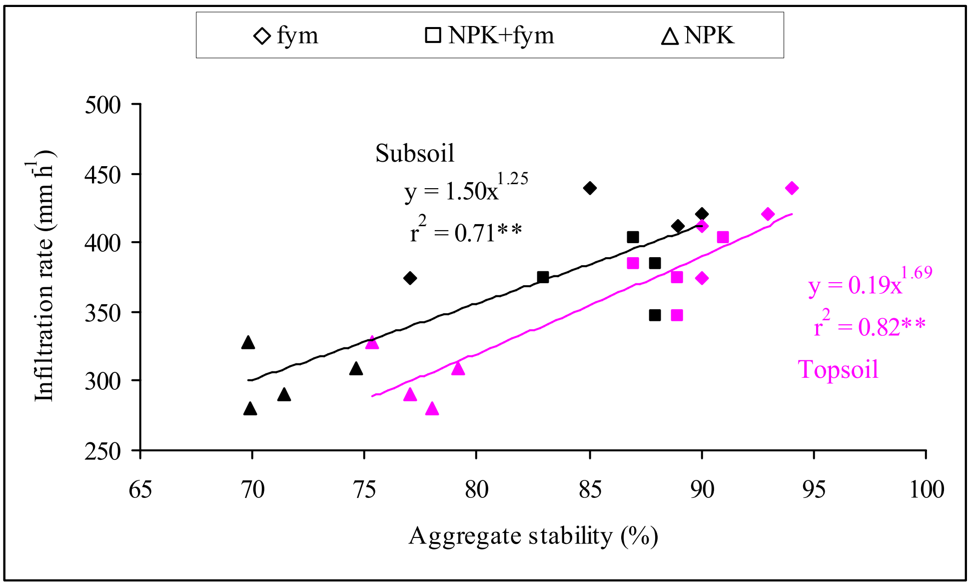


Fig. 3.39: Relationship between soil infiltration rate and soil aggregate stability as influenced by different fertilization treatments (site Braunschweig, Field No. 36, 2006; sampling depths 0-25 cm and 25-50 cm) (Significance: *= $p < 0.05$, **= $p < 0.01$, ***= $p < 0.001$, ns = not significant)

Figure 3.39 shows that the soil infiltration rate was significantly affected by the soil aggregate stability and fertilization management. The relationship between soil infiltration rate and soil aggregate stability is stronger in the topsoil in comparison to the subsoil.

3.4.4 Dehydrogenase activity

The organic and mineral fertilization influenced the dehydrogenase activity of soil considerably (Figure 3.40).

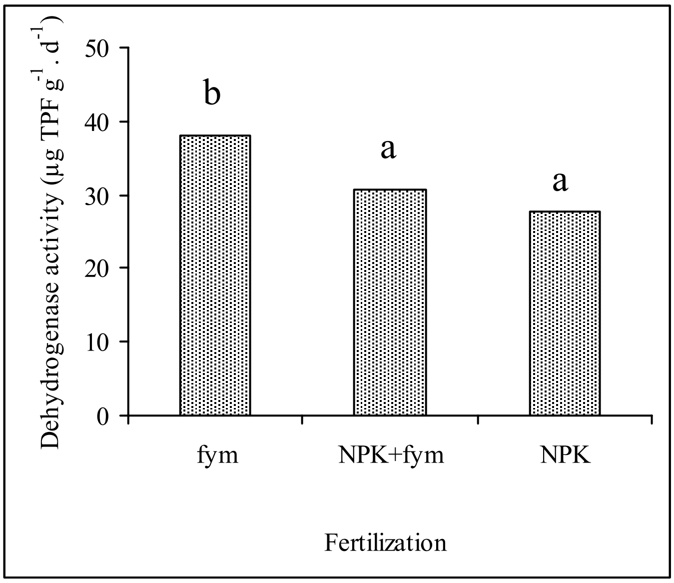


Fig. 3.40: Dehydrogenase activity of soil as affected by different fertilization treatments (site Braunschweig, Field No. 36, 2006, crop: rapeseed, sampling depth 0-30 cm)
Mean values followed by the same letters are not significantly different by Duncan's test at the 0.05 level.

The dehydrogenase activity was significantly higher in the organic-fertilized plot (fym) compared to the mineral-fertilized plot (NPK). That result was because of the proportional relationship between the soil organic carbon and soil water content. The organic fertilization leads to a higher content of soil organic matter, which can store a greater content of soil water resulting in a higher dehydrogenase activity compared to the mineral fertilization. It can be deduced that the organic fertilization led to a nearly 10 % higher dehydrogenase activity compared to the mineral fertilization.

3.4.5 Earthworms

The investigated fertilization treatments obviously influenced the earthworm population, where clear differences have been observed in earthworm abundance and biomass between the differently fertilized plots as shown in Figure 3.41.

.

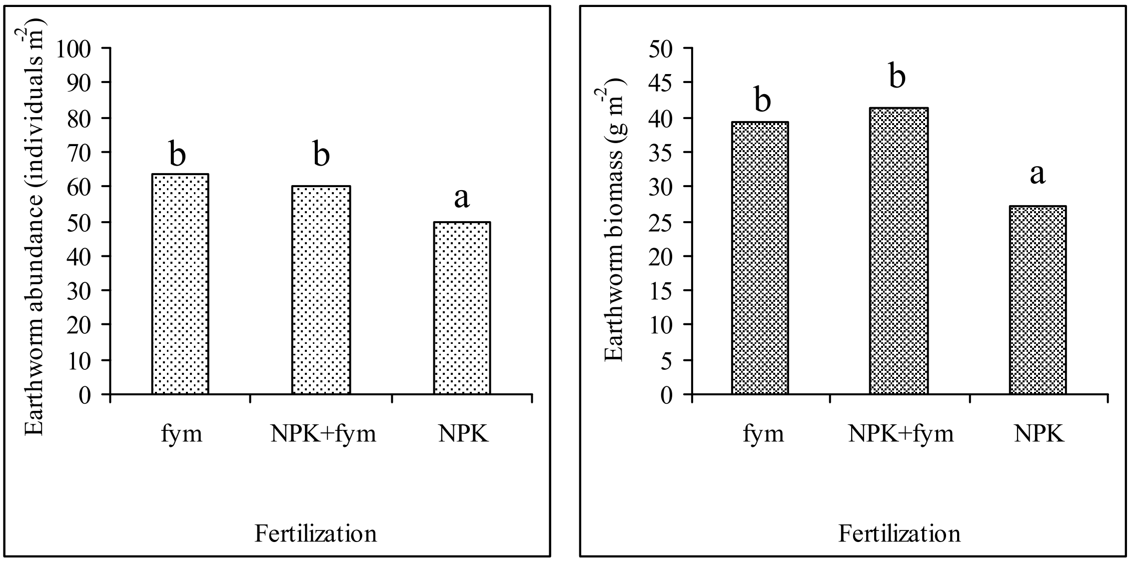


Fig. 3.41: Earthworm abundance and biomass as affected by different fertilization treatments (site Braunschweig, Field No. 36, crop: rapeseed, 2006)

Mean values followed by the same letters are not significantly different by Duncan's test at the 0.05 level.

It was found that earthworm abundance and biomass were significantly greater in the organic-fertilized plot (fym) and the combined-fertilized plot (NPK+fym) compared to the mineral-fertilized plot (NPK). No significant differences were observed in earthworm abundance and biomass between the organic-fertilized plot (fym) and the combined-fertilized plot (NPK+fym). It can be noticed that the organic fertilization led to a nearly 15 % higher earthworm abundance and 10% higher earthworm biomass compared to the mineral fertilization. The higher earthworm abundance and biomass are attributed to the higher content of soil organic carbon in the treatments with farmyard manure. The age structure and the ecological groups of the earthworm population were influenced by fertilization treatments (Table 3.14).

Tab. 3.14: Age structure and ecological groups of earthworm population as affected by different fertilization treatments (site Braunschweig, Field No. 36, 2006)

Fertilization	Age structure		Ecological groups		
	Juvenile	Adult	Epigeic	Endogeic	Anecic
	Individuals m^{-2}				
fym	31 a	33 b	15 b	37 b	12 b
NPK+fym	37 a	23 a	6 a	40 b	14 b
NPK	30 a	20 a	17 b	27 a	6 a

Mean values followed by the same letters are not significantly different by Duncan's test at the 0.05 level.

The results have revealed that no significant differences were found in the number of juvenile individuals between the differently fertilized plots. The number of adult individuals was significantly higher in the organic-fertilized plot (fym) compared to the mineral-fertilized plot (NPK). It was found that the numbers of endogeic and anecic individuals were significantly higher in the organic-fertilized plot (fym) and the combined-fertilized plot (NPK+fym) compared to the mineral-fertilized plot (NPK). The number of epigeic individuals showed no definite impact of the fertilizer application.

The composition of earthworm population plays an important role for the infiltration potential. The relationship between soil infiltration rate and earthworm abundance, as well as the relationship between soil infiltration rate and earthworm biomass, are shown in Figures 3.42 and 3.43.

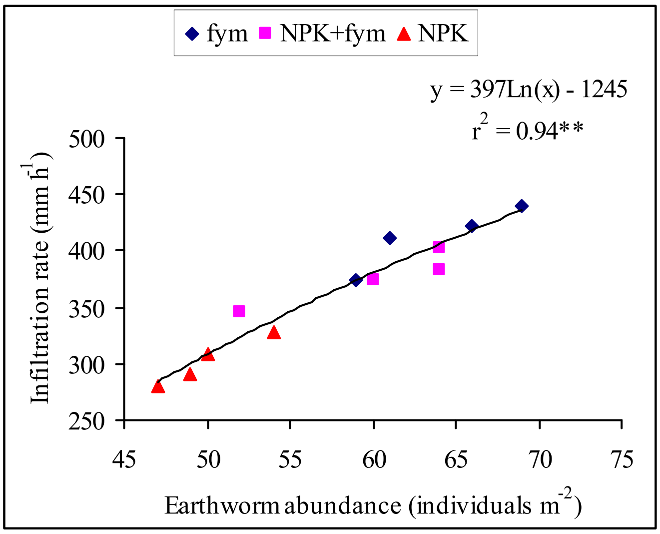


Fig. 3.42: Relationship between soil infiltration rate and earthworm abundance as influenced by different fertilization treatments (site Braunschweig, Field No. 36, 2006)

(Significance: *= $p < 0.05$, **= $p < 0.01$, ***= $p < 0.001$, ns = not significant)

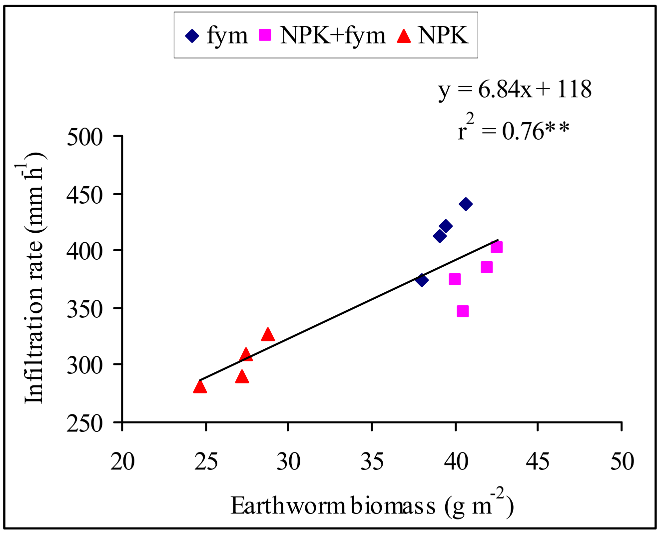


Fig. 3.43: Relationship between soil infiltration rate and earthworm biomass as influenced by different fertilization treatments (site Braunschweig, Field No. 36, 2006)
(Significance: *= $p < 0.05$, **= $p < 0.01$, ***= $p < 0.001$, ns = not significant)

According to the last two figures above, earthworm abundance and biomass had a significant role in enhancing the water infiltration rate in the soil. In this context, the soils with a high earthworm activity generally can support elevated water infiltration rates. It was found that the relationship between the infiltration rate and earthworm abundance was stronger in comparison to earthworm biomass. Hence, based on the relationship between the infiltration rate and earthworm abundance in this chapter and in the former chapters, it can be deduced that earthworm abundance has a greater effect on improving the water infiltration rate in the soil compared to earthworm biomass.

3.4.6 Soil chemical properties

The different fertilization treatments markedly influenced the soil nutrient content of the studied plots as listed in Table 3.15. The upper topsoil analysis (0-8 cm) is shown because the nature of this soil layer is of high importance to guarantee an unlimited infiltration potential.

Tab. 3.15: Soil nutrient content as affected by different fertilization treatments (site Braunschweig, Field No. 36, 2006, crop: rapeseed; sampling depth 0-8 cm)

Fertilization	**C**	**N**	**pH**	**P**	**K**	**Mg**
	%	**%**		**mg kg^{-1}**	**mg kg^{-1}**	**mg kg^{-1}**
fym	1.38	0.087	5.9	64	263	60
NPK+fym	1.41	0.080	5.8	208	182	-
NPK	1.29	0.086	5.4	51	203	35

* Mg value for the combined-fertilized plot was not available.

According to Table 3.15, the soil organic carbon content was higher in the organic-fertilized plot (fym) and the combined-fertilized plot (NPK+fym) compared to the mineral-fertilized plot (NPK). The increased carbon stock is a precondition for a high earthworm population and furthermore for an unlimited potential of water infiltration into the soil profile (compare Fig. 3.36).

The soil pH, Mg and K content were higher in the organic-fertilized plot (fym) than in the mineral-fertilized plot (NPK). Also, the soil P content was higher in the organic-fertilized plot (fym) and the combined-fertilized plot (NPK+fym) than in the mineral-fertilized plot (NPK). No considerable differences were determined in the soil N content.

3.5 Interactions between factors affecting the infiltration capacity of soils

The results demonstrated in the previous chapters showed that land use, farming system, soil tillage and fertilization influenced important soil properties, and finally, the infiltration potential of soils. However, the quantification of interactions between factors affecting the infiltration rates requires a major data mining. Therefore, the complete database of the particular site was used for further calculations.

Regression and correlation analyses were employed to identify the relationship between soil properties (as influenced by agricultural management) and the infiltration rates. Principal Component Analysis (PCA) was a useful way to identify patterns in data and to highlight their similarities and differences. These statistical analyses were performed for each experimental site separately and for all experimental sites together.

Site Braunschweig

The PCA for the Braunschweig site extracted four principal components (PC_S) based on the method of data reduction or structure detection (Table 3.16). As shown in Table 3.16 the studied factors can be reduced to four principal components, which account for 92 % of the total variance. PC 1 accounted for 49 % of the variability, PC 2 accounted for 17 %, PC 3 accounted for 15 %, and PC 4 accounted for 11 % of the variability.

Tab.3.16: Results of the rotated component matrix for the studied factors in Braunschweig including factor loadings and variance values for each principal component

Factor	Principal Components (PC)			
	PC 1	PC 2	PC 3	PC 4
Silt (topsoil) (%)	0.884	0.139	-0.193	-0.223
Earthworm biomass (g m^{-2})	0.873	0.360	-0.240	-0.107
Earthworm abundance (worms m^{-2})	0.873	0.355	-0.278	-0.126
Sand (topsoil) (%)	-0.865		0.337	0.219
Dehydrogenase activity (µgTPFg^{-1}.d^{-1})	0.864	-0.128	0.187	0.331
Stability 25-50cm (%)		0.946		
Stability 0-25cm (%)	0.317	0.912	0.121	
Bulk density 18-24cm (g cm^{-3})		-0.787	0.539	
Bulk density 10-16cm (g cm^{-3})		-0.744	0.635	
Carbon stock (t ha^{-1})	0.288	0.714	-0.497	-0.348
Infiltration rate (mm h^{-1})	0.519	0.555	-0.542	-0.295
Bulk density 26-32cm (g cm^{-3})	-0.184	-0.280	0.841	-0.232
Clay (topsoil) (%)	0.201	-0.176	-0.832	
Bulk density 2-8cm (g cm^{-3})	-0.315	-0.592	0.655	0.182
Sand (subsoil) (%)				-0.972
Silt (subsoil) (%)			-0.143	0.953
Clay (subsoil) (%)	-0.203		0.435	0.769
Explained variance	**49.04**	**16.86**	**14.90**	**10.84**
Sum	**49.04**	**65.90**	**80.80**	**91.64**
	Soil biology	Soil function & soil structure		Soil texture

The high loadings of the first component (PC 1) express a combination of soil biological properties (earthworm abundance and biomass as well as the dehydrogenase activity (DHA)) and soil physical properties (soil texture, infiltration). There were significant correlations between these variables. Soil biological properties were positively correlated with the silt content while negatively correlated with the sand content (Table A.11). PC 1 can be characterized as “soil biology”. PC 2/ PC 3 represent the “soil function” and “soil structure” dominated by the aggregate stability, the bulk density, the carbon stock and the infiltration rate. These variables cover a wide range of loadings (0.5 – 0.9). The infiltration rate was significantly correlated with the bulk density and carbon stock. The soil bulk density was negatively correlated with other variables such as the clay content (see Table A.11). PC 4 reflected the mostly negative correlations between sand, silt and clay in the soil (Table A.11). High loadings (> 0.7) of PC 4 may be summarized as “soil texture”.

The identified patterns of PCA were also related to the results of the regression analysis.

The significant factors affecting the soil infiltration in Braunschweig involve soil properties, which characterize soil biology, soil structure and soil texture (Table 3.17).

Tab. 3.17: Relationship between soil properties (x_i) and the infiltration rate (mm h^{-1}) of soil (y) (site Braunschweig, 2006)

	Infiltration = f(x_i)				
x_i	***Function type***	***b_0***	***b_1***	***r^2***	***df***
Carbon stock (t ha^{-1})	Exponential	12.49	0.057	0.40	38
Bulk density (2-8 cm) (g cm^{-3})	Exponential	18200.5	-3.462	0.28	38
Bulk density (10-16 cm) (g cm^{-3})	Exponential	889856	-5.935	0.17	38
Bulk density (18-24 cm) (g cm^{-3})	Exponential	491324	-5.511	0.21	38
Bulk density (26-32 cm) (g cm^{-3})	Exponential	1427466	-6.166	0.18	38
Earthworm abundance (worms m^{-2})	Power	0.482	1.579	0.89	20
Earthworm biomass (g m^{-2})	Power	2.081	1.376	0.87	20
Sand (subsoil) (%)	Power	6.00E-06	4.452	0.28	38
Silt (subsoil) (%)	Power	4.10E+09	-4.456	0.27	38

All the significant selected variables listed in Table 3.17, except of the variables “earthworm biomass” and “silt (subsoil)”, have been used in the multiple regression analysis. The variables “earthworm biomass” and “silt (subsoil)” have been rejected from the multiple regression analysis. That is because high intercorrelations were noted between “earthworm abundance” and „earthworm biomass” in addition to high intercorrelations between ”sand (subsoil)” and “silt (subsoil)” (Table A.11). Hence, the variables ”earthworm abundance” and “sand (subsoil)” have been accepted for the multiple regression analysis as more effective variables on the soil infiltration compared to “earthworm biomass” and “silt (subsoil)”.

The results of the multiple regression analysis for significant factors affecting the soil infiltration are demonstrated in Table 3.18.

Tab. 3.18: Results of the multiple regression analysis for significant factors affecting the soil water infiltration in Braunschweig

		Model parameter								
		Constant	C	DBD1	DBD 2	DBD3	DBD 4	EWA	$SAND_{sub}$	R^2
Model 1	b_i	-472	13.3	51.5	329	86.7	-491	1.70	0.52	0.977
	Beta		0.895	0.039	0.211	0.052	-0.224	0.270	0.020	
Model $_{sig}$	B	-455	13.4		439		-460	1.63		0.976
	Beta		0.900		0.281		-0.210	0.259		

C = carbon stock (t ha^{-1}), DBD 1 = bulk density (2-8 cm) (g cm^{-3}), DBD 2 = bulk density (10-16 cm) (g cm^{-3}), DBD 3 = bulk density (18-24 cm) (g cm^{-3}), DBD 4 = bulk density (26-32 cm) (g cm^{-3}), EWA = earthworm abundance (worms m^{-2}), $SAND_{sub}$ = sand of subsoil (%)

As shown in Table 3.18, Model 1 included the variables selected on the basis of single regression analysis as significant to prove their influence on the infiltration. The significant model (model $_{sig}$) comprised the most important factors affecting the soil infiltration. The most important influences on the infiltration can be explained by the “Beta” values. In the case of Model 1 and model $_{sig}$, the carbon stock had the highest influences on the infiltration rate, followed by the soil dry bulk density and earthworm abundance.

Sites Trenthorst and Mariensee

The data of Trenthorst and Mariensee sites were regressed together because they are off-farm experiments at meso-scale. This was necessary because of limited data sets of single sites. Through this procedure, it was possible to conduct the multiple regression analysis. From the variables, the carbon stock and the number of earthworms, the quotient number of earthworms per tons carbon stock was derived with the aim of recognizing the complex causal relationships in soils.

The PCA for the sites Trenthorst and Mariensee together produced three principal components (PC_S) based on the method of data reduction or structure detection (Table 3.19). As shown in Table 3.19, the studied factors were reduced to three principal components, which account for 86 % of the total variance. PC 1 accounted for 42 % of the variability, PC 2 for 27 % and PC 3 accounted for 17 % of the variability.

Tab.3.19: Results of the rotated component matrix for the studied factors in Trenthorst and Mariensee including factor loadings and variance values for each principal component

Factor	**Principal Components (PC)**		
	PC 1	**PC 2**	**PC 3**
Infiltration rate (mm h^{-1})		0.319	0.766
Earthworm/C stock (earthworms per tons carbon)		0.138	0.910
Aggregate stability 0-25cm (%)	-0.332	0.327	-0.537
Bulk density 18-24cm (g cm^{-3})		0.944	0.132
Bulk density 26-32cm (g cm^{-3})	-0.158	0.963	0.139
Sand (topsoil) (%)	-0.989	0.121	
Silt (topsoil) (%)	0.910	-0.332	
Clay (topsoil) (%)	0.986		
Explained variance	**42**	**27**	**17**
Sum	**42**	**69**	**86**
	Soil texture	Soil structure & soil function	

The high loadings of the first component (PC 1) can be expressed as “soil texture”. PC 2/ PC 3 indicate a combination of soil chemical / biological properties (earthworm abundance and carbon stock) and soil physical properties (infiltration, bulk density and aggregate stability). There were significant correlations between the infiltration rate and further soil properties (see Table A.12). The strongest relationship between soil properties and the infiltration rate in Trenthorst and Mariensee could be demonstrated for the variable earthworm abundance per carbon stock (Table 3.20). The computed r² values are quite low for the single regression analysis because the infiltration rate is influenced by numerous parameters and not only individual soil properties.

Tab. 3.20: Relationship between soil properties (x_i) and the infiltration rate (mm h^{-1}) of soil (y) (site Trenthorst and Mariensee, 2006)

Infiltration = f(x_i)					
x_i	***Function type***	***b_0***	***b_1***	***r^2***	***df***
Carbon stock (t ha^{-1})	Power	7348	-0.588	0.32	26
Earthworm/C stock (earthworms per tons carbon)	Exponential	314	0.391	0.47	26

The variables used in the multiple regression analysis are not intercorrelated (see Table A.12). This is a basic precondition for reliable evaluations. The results of the multiple regression analysis for relevant factors affecting soil infiltration rates are summarized in Table 3.21.

Tab. 3.21: Results of the multiple regression analysis for relevant factors affecting the soil water infiltration in Trenthorst/ Mariensee

		Model parameter							
		constant	EW/C	AGSTAB1	DBD 3	DBD 4	SILT $_{top}$	CLAY $_{top}$	R²
Model 1	b_i	14209	485	2110	-1131	-7327	-140	136	0.87
	Beta		1.09	0.88	-0.13	-1.24	-2.92	2.79	
Model $_{sig}$	B	14462	492	2214		-8543	-147	142	0.87
	Beta		1.11	0.92		-1.45	-3.08	2.92	

EW/C = Earthworm/C stock (earthworms t^{-1}C), AGSTAB1 = aggregate stability (topsoil) (%), DBD 3 = bulk density (18-24cm) (g cm^{-3}), DBD 4 = bulk density (26-32 cm) (g cm^{-3}), SILT $_{top}$ = silt of topsoil (%), CLAY $_{top}$ = clay of topsoil (%)

As shown in Table 3.21, the significant model (model $_{sig}$) included the most important factors affecting soil infiltration rates in the sites Trenthorst and Mariensee. As already mentioned, the most important influences on the infiltration can be illustrated by the “Beta” values. In the case of Model 1 and model$_{sig}$, the soil textural classes (silt and clay content of the topsoil) had the highest influences on the infiltration rate, followed by the soil dry bulk density and the earthworm abundance per carbon stock, as well as the aggregate stability.

More than 80 % of the infiltration variability can be explained by these parameters.

3.6 Selection of model algorithms to describe the indicator "infiltration" and to develop infiltration scenarios

The influence of the variables - quotient of earthworm numbers per tons carbon stock, the aggregate stability of the topsoil, the bulk density at 18-24 cm soil depth and the sand content of the topsoil- on infiltration rates was analyzed by the linear multiple regression analysis for all the experimental sites together ($r^2 = 0.60$). The beta values show clearly that the number of earthworms per tons carbon stock and the aggregate stability dominate the relationship and are the most influential variables (Table. 3.22).

Tab. 3.22: Suitable model algorithms to describe the indicator infiltration [mm h^{-1}] (all data sets, N = 50)

		Model parameter					
		constant	EW/C	AGSTAB 1	DBD 3	SAND $_{top}$	R^2
Model algorithms	b_i	-237	362	450	-75.99	-1.03	0.60
	Beta		0.78	0.15	-0.02	-0.03	

EW/C = Earthworm/C stock (earthworms t^{-1}C), AGSTAB 1 = aggregate stability (topsoil) (%) DBD 3 = bulk density (18-24 cm) (g cm^{-3}), SAND $_{top}$ = sand of topsoil (%)

The best-fit correlation between analyzed and calculated infiltration rates for all the investigated long-term field experiments and off-farm observations allows the conclusion that the water infiltration into the soil profile can be estimated from the soil carbon stock, the earthworm abundance, the aggregate stability, the bulk density and the sand content (Fig. 3.44). The calculation is not as strong as expected, because of the different complex effects of soil structures, e.g., soil properties dominated by biopores as preferential pathways. That can be seen especially in the data of the Trenthorst site (organic-managed Field O3). The high measured infiltration rates are inherent to the organic farming system and cannot be sufficiently reflected by the chosen model algorithms.

Nevertheless, it is possible to create scenarios which allow the characterization of the causal relationships between factors affecting the infiltration capacity of agricultural soils.

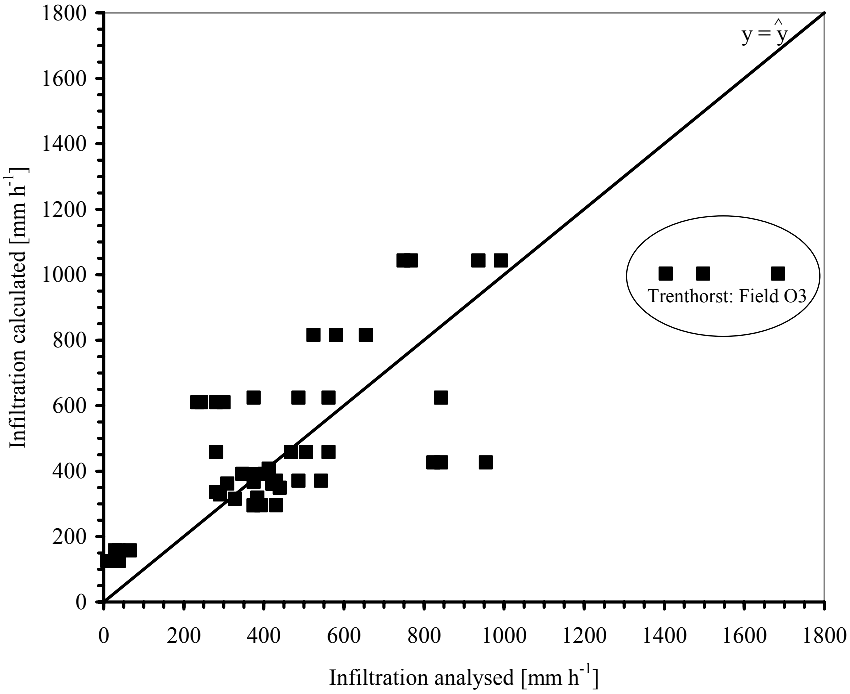


Fig. 3.44: Relationship between analyzed and calculated infiltration rates (all data sets of the experimental sites Braunschweig, Trenthorst and Mariensee, basis of calculation: equation Tab. 3.22)

Based on model parameters, demonstrated in Table 3.22, the following infiltration scenarios (Table 3.23) were derived. As mentioned above the number of earthworms per tons of carbon stock as well as the aggregate stability are the determining factors for water infiltration into the soil profile. The low influence of the soil bulk density and the sand content on the water infiltration is evidence of the complexity of ecological soil processes and the importance of soil structure. The level of water infiltration is obviously determined by preferential flow paths, caused by the earthworm activity and composition. On the other hand, this relationship cannot be considered without the carbon stock of soil.

Tab. 3.23: Scenarios based on the multiple linear regression analysis to quantify the influence of soil properties on infiltration rates (dark: low, white: medium, light: high)

EW/C	DBD 3	AGSTAB 1: low		AGSTAB 1: medium		AGSTAB 1: high	
		$SAND_{top60}$	$SAND_{top30}$	$SAND_{top60}$	$SAND_{top30}$	$SAND_{top60}$	$SAND_{top30}$
		relative infiltration rates (100 % = 500 mm h^{-1})					
very low	high	0	3	15	21	33	39
	low	0	6	17	23	35	41
low	high	33	39	51	57	69	75
	low	35	42	53	59	71	77
medium	high	105	111	123	129	141	147
	low	107	114	125	131	143	149
high	high	177	183	195	201	213	219
	low	179	186	197	203	215	221

AGSTAB 1: Aggregate stability, low 0.5, medium 0.7, high 0.9

DBD 3: Dry bulk density, low 1.45 g cm^{-3}, high 1.60 g cm^{-3} at 18-24 cm depth

EW/C: Earthworm/ C stock, very low 0.5 earthworms t^{-1}C, low 1.0 earthworms t^{-1}C,
medium 2.0 earthworms t^{-1}C, high 3.0 earthworms t^{-1}C

$SAND_{top}$: 30 or 60 % sand in the topsoil

4 Discussion and conclusions

Water flooding induced by heavy rainfalls or river floods is still considered a serious problem at the present time. Frequent floods can generate a real threat to agricultural soils. In particular, floods can lead to soil erosion induced by the high surface runoff. In addition, floods may result in loss of homes and a lot of other damages. Commonly, prevention of temporal flooding events is an impossible task. Mitigation of the negative impacts of flood tends to be a plausible aim. In this context, the water infiltration capacity of soil was looked at as a very important means to reduce the surface runoff, by increasing the flow of water into the soil, and thus enhance soil protection against water erosion.

The main aim of the present work was to identify the most important factors affecting the infiltration capacity of agricultural soils as a conservation method of soils against the flooding produced by either rivers or heavy precipitation. The discussion of work results focused on the evaluation of the main factors like land use, farming system, soil tillage and fertilization treatments, which strongly influence soil properties leading to changes in the infiltration capacity of agricultural soils (Chapter 4.1). The problem of silent sealing of arable lands and its negative impacts on the soil infiltration capacity are discussed in Chapter 4.2. In addition, the discussion evaluates the infiltration capacity as a protection indicator of soil (Chapter 4.3).

4.1 Evaluation of factors affecting the water infiltration capacity of agricultural soils

4.1.1 Land use

There was a distinct variation in the infiltration capacity caused by different land use systems. Arable soils are characterized by lower infiltration rates compared to forest and natural succession (Fig. 3.1). These results correspond to a research by Hartge (1988) who reported that land use controls soil infiltration. The variation of infiltration was produced due to the variance of effect on soil properties by land use systems. The highest infiltration rate noted in the forest soil was due to a higher content of soil organic matter and an improved soil structure as well as a high fraction of macro-pores produced by the root activity (Mapa, 1995). This result is in agreement with the study of Mann and Tolbert (2000) who revealed that the great development of roots at deeper depths in the soil provides a higher soil stability and results in more pathways for water infiltration. Heermann and Duke (1983) reported that the presence of litter layers on the soil surface of forest retards the surface runoff and provides more time for water to infiltrate into the soil.

The natural succession soil had a higher infiltration rate compared to arable land. This result agreed with research by Ernest and Tollner (2002) who deduced that the infiltration rate is higher under grass compared to field crops. This is attributed to the higher soil compaction in arable lands due to a high stress induced by field traffic and possibly also by overgrazing and hence they had a higher soil dry bulk density and decreased infiltration rates. The natural succession land is normally under no tillage or mechanical stress, and thus has a less compaction, a lower soil dry bulk density and increased infiltration rates. This interpretation goes along with Hillel (1982) who revealed that the compaction could reduce the largest soil pores resulting in a diminished infiltration rate. On the other hand, the perennial grass produces a greater amount of plant biomass in the soil, leading to a higher accumulation of the surface organic matter, which in turn contributes to enhanced infiltration rates, compared to the annual vegetation (Wienhold and Tanaka, 2000). In addition, the natural succession provides a permanent soil cover that in turn decreases the negative impact of raindrops on the soil surface, and declines the surface runoff rate, giving more time for infiltration (Unger, 2002).

It was observed that earthworms were completely absent in the forest soil. This is due to an inadequate soil pH with values of less than 4.0 (see Table A.2). This result supported the research of Edwards and Bohlen (1996) who revealed that earthworms are strongly affected by the soil pH. Edwards and Lofty (1977) reported that earthworms commonly would not succeed in a soil with a pH less than 5.

The natural succession soil had a higher earthworm abundance and biomass than arable land (Fig. 3.8 and Fig. 3.9). This result came accordant to the studies of Ramsay and Hill (1978) which illustrated that the highest abundance of earthworms occurs in the natural succession, while arable lands normally have intermediate numbers of earthworms. This might be attributed to a higher content of soil organic matter in the natural succession as compared to arable lands. Earthworm abundance and biomass are positively associated with the amount of organic matter in the soil (Edwards and Bohlen, 1996). The higher earthworm numbers and biomass contributed to higher infiltration rates in the natural succession soil compared to arable land. This finding is well proved by the work of Edwards et al. (1988), who reported that increased soil infiltration rates are correlated with a high earthworm activity in the soil. This is because earthworms produce vertical macro-pores with a high continuity in the soil, which provide water flow paths causing increased infiltration rates (Rogasik et al., 2004). The higher soil infiltration rates were accompanied by a higher soil aggregate stability in the forest and natural succession compared to arable land (Fig. 3.5). This result is in accordance with Schnug and Haneklaus (2002) who indicated the relationship between the improved soil mechanical stability and increased infiltration rates of soil. The high soil aggregate stability established in the forest and natural succession was due to a high content of soil organic carbon (Le Bissonnais and Arrouays, 1997).

Besides high infiltration rates, the high aggregate stability provided an additional potential to the forest and natural succession soils as a preservation factor against the water erosion. The facts mentioned above lead to several deductions. Forests, by the limitation of surface water runoff induced by litter layers on the soil surface in addition to high numbers of macropores and channels produced by the huge root activity, can be characterized as the most important land use for enhanced soil infiltration rates as compared to the natural succession and arable land. The natural succession, with a high content of soil organic matter, as well as a great earthworm abundance and biomass, can be considered as a very important land use for increased soil infiltration rates in comparison to arable land. Therefore, reforestation of endangered soils or conversion to a natural succession becomes an objective procedure to protect agricultural soils against the water erosion induced by a flooding during heavy rainfalls or by river floods.

4.1.2 Farming system

The studied farming systems influenced the water infiltration into the soil profile to a great extent. The organically managed field (Field O3) had a higher soil infiltration rate compared to the conventionally managed field (Field C1) (Fig. 3.12). The increased infiltration rate in Field O3 resulted from improved soil fertility. Poudel et al (2001) demonstrated that organic farming leads to a better soil structure and higher biological activity and greatly supports water infiltration rates of soil. It was noted that the higher soil infiltration rates were associated with a higher soil aggregate stability and a higher number of macro-pores (soil pores with a diameter >50 µm) in Field O3 compared to Field C1 (Chapter 3.2). This result was well documented by the work of Mapa and Gunasena (1995), who illustrated that the higher aggregate stability produces a higher macro-porosity in the soil, which in turn results in a higher soil infiltration rate.

The increased soil infiltration rate was caused by a greater earthworm number and biomass in Field O3 compared to Field C1 (Fig. 3.20 and Fig. 3.21). The greater earthworm number and biomass played an effective role in increasing the infiltration rate of soil. In particular, Field O3 is characterized by a higher number of “anecic” earthworms, which create vertically continuous burrows with a high potential for infiltration. This fact was documented by Schnug et al (2004) who explained that organic farming results in a greater number and biomass of earthworms producing more "biopores" in the soil, and hence higher infiltration rates in comparison to conventional farming. The presence of bio-macropores is essential to support water infiltration rates in the soil and may enhance the infiltration rate by a factor of ten (Smettem et al., 1999). On the other hand, it is well known that organic farming never uses pesticides, which adversely affect earthworms. Therefore, organic farming is safer and more useful for earthworm populations in comparison to conventional farming.

It can be concluded that the organic farming system, due to the improved soil structure and the higher biological activity, is a more effective strategy to guarantee higher infiltration rates compared to the conventional farming system. However, organic farming, with a high infiltration potential, can be considered as a promising precautionary measure for protecting agricultural soils against the water erosion induced by extraordinary precipitations or river floods.

4.1.3 Soil tillage

The present work revealed that the different soil tillage systems and tillage intensities influenced the water infiltration into the soil significantly. The work results supported that soil infiltration rates under shallow tillage were higher than under deep tillage (Fig. 3.24). This result is in agreement with Wuest (2001). The differences observed in the infiltration rates were a consequence of the changes in soil physical, chemical and biological properties induced by different tillage treatments (Pelegrin et al., 1990). Shallow tillage reduced the soil penetration resistance as well as the dry bulk density only in the surface layer of soil, whereas deep tillage decreased the soil dry bulk density in the deeper soil layers (Fig. 3.26). Nevertheless, shallow tillage produced higher infiltration rates than deep tillage. This result can only be explained by the interaction of soil physics and soil biota. The influence of soil tillage on infiltration rates should be considered from the viewpoint of the loosening effect and the impact of earthworm abundance. As the soil water infiltration is directly associated with the soil pore structure (Ankeny et al. 1990; Madeira et al., 1989), it can be deduced that the higher infiltration rates of shallow tillage, in comparison to deep tillage, are a result of the vertical continuity and connectivity of biopores.

Soil tillage intensity affects the distribution of macropores resulting in changes in the soil infiltration potential (Logsdon et al., 1990). Moreover, earthworms have an essential impact on the soil structure and porosity, and can largely increase the water infiltration into the soil (Bowman, 1993). The higher infiltration rates could be related to a higher earthworm activity under shallow tillage where a greater earthworm abundance and biomass (about twofold) was observed, in particular a higher number of deep earthworms ”anecic”, in comparison to deep tillage (Fig. 3.30 and Table 3.11). This is in agreement with Aura (1999) and Chan (2001), who found that shallow tillage stimulates more “anecic” earthworm species and conserves their continuous pores under the cultivated soil layer, which in turn promote higher soil infiltration rates. In this context, it can be stated that the reductions of soil infiltration rates observed under deep tillage are traced back to the destruction of earthworm burrows induced by intensive tillage (Werner, 1990). As soil tillage can induce drastic changes in the earthworm populations (Chan, 2001), shallow tillage enhances the attendance of earthworms and provides a larger earthworm population as compared to deep tillage (Deibert et al., 1991). This is related to less mechanical damage to earthworms during tillage in addition to a higher content of soil water, induced by a less soil disturbance with shallow tillage as contrasted to deep tillage (Chan, 2001).

On the other hand, it was clear that the higher infiltration rates are the result of a distinctly higher soil aggregate stability under shallow tillage, in contrast to deep tillage (Chapter 3.3). This took place because shallow tillage results in the concentration of organic matter in the topsoil, producing a high soil aggregate stability (Kouwenhoven et al., 2002), which in turn, according to Mapa and Gunasena (1995), enhances the soil porosity promoting more water infiltration through the soil. Also, earthworms, by their casts, can take part in the soil aggregate formation and the stabilization of soil structure (Oades, 1993). As mentioned several times above, the higher soil aggregate stability is attributed to a greater earthworm population under shallow tillage.

The dehydrogenase activity was higher under shallow tillage than under deep tillage (Fig. 3.29). This finding can be explained by the fact that soil tillage treatments govern the microbial biomass and the enzymatic activity of soil because tillage can alter the ratio of organic matter and nutrient content required for the soil biological activity (Perucci, 1990).

Thus, shallow tillage caused less change to the soil factors connected to the biological activity, resulting in a higher soil dehydrogenase activity as contrasted to deep tillage (Curci et al., 1997). It can be summarized that shallow tillage achieved more improved soil physical properties (a better soil structure with continuous biopores). In addition, shallow tillage achieved more enhanced soil biological properties (larger earthworm abundance and biomass, especially a higher number of “anecic“earthworms, as well as a higher dehydrogenase activity), and an increased content of soil organic matter, and consequently higher infiltration rates as compared to deep tillage.

Conservation tillage yielded higher infiltration rates as contrasted to conventional tillage (Fig. 3.24). This result is consistent to the work of Tebrügge and Düring (1999), who illustrated that conservation tillage often produces more enhanced infiltration rates as compared to conventional tillage. The increase of infiltration rates was due to greater improvement of soil properties obtained under conservation tillage in contrast to conventional tillage (Buschiazzo et al., 1998). For instance, conservation tillage produces a higher vertical connectivity and continuity of soil macropores than conventional tillage. (Hangen et al., 2002).

As soil infiltration rates are governed by the pore size distribution and the continuity of soil macropores (Kutilek, 2004), and since enhanced soil infiltration rates are associated with a larger number of soil macropores (Edwards et al., 1988), conservation tillage contributed to a higher infiltration potential in comparison to conventional tillage. Shipitalo et al. (2000) supported that the amount of rainfall flowing in macropores, which are mostly related to the biopores formed by earthworms, is larger under conservation tillage than under conventional tillage.

The larger numbers of macropores and the greater vertical continuity of macropores are traced back to higher earthworm numbers and less disturbance of soil under conservation tillage compared to conventional tillage (Buczko et al., 2003). This opinion is supported by many studies. Zachmann et al (1987) indicated that conservation tillage with increased surface crop residues results in greater earthworm activity than conventional tillage because surface residues afford a useful food origin for earthworms and provide protection to their surface environment. The larger earthworm population was due to the presence of surface residues, a suitable content of soil moisture and less soil disturbance (Chan, 2001).

Commonly, the higher intensity of soil tillage leads to a lower earthworm abundance and biomass (Lee, 1985; Mackay and Kladivko 1985) whereas, the earthworms activity can be enhanced by less intensive tillage treatments that leave crop residues on the soil surface

(Aubum, 2001). Thus, reduced tillage improves earthworm populations and intensifies the numbers of continuous macropores in the soil enhancing the water infiltration into the soil (Edwards et al., 1988). Besides, Schrader et al (1995) reported that earthworms, by their casting and burrowing activities, could change the soil porosity creating a net of macropores, which serve as useful pathways for the water infiltration into the soil.

The results of the present work indicated a greater soil aggregate stability and a higher organic matter content under conservation tillage compared to conventional tillage (Chapter 3.3). This result is well proved by Wright et al (1999) and Lipiec et al (2006). As the soil aggregate stability is positively related to the soil organic matter content (Tisdall and Oades, 1980), the higher soil organic matter content increased the soil aggregate stability under conservation tillage. The higher soil organic matter content under conservation tillage was due to leaving crop residues on the soil surface, which results in a greater concentration of organic matter in the topsoil (Tebrügge and Düring, 1999). Thus, conservation tillage, with maintaining the surface crop residue, can achieve a high soil structural stability, decrease the soil surface sealing, reduce the prospect of plough pans formation and elevate the water infiltration potential (Rogasik et al., 2004). In contrast, conventional tillage leads to a reduction of the soil organic matter content, a loss of the mechanical stability as well as soil compaction resulting in negative impacts on the soil water infiltration (Hermawan and Cameron, 1993).

It can be summarized that conservation tillage, with a high input of surface crop residues, achieved a better soil physical condition (a higher soil mechanical stability and a greater number of macropores with a high vertical continuity). In addition, conservation tillage resulted in more improved soil biological properties (greater earthworm populations) and a larger soil organic matter content, and hence higher rates of water infiltration into the soil. Therefore, it can be deduced that shallow and conservation tillage, through maintaining elevated water infiltration possibilities, could offer means to protect agricultural soils against flooding-induced water erosion.

4.1.4 Fertilization

The infiltration measurement results in the present research revealed considerable variations of the infiltration rates depending on different fertilization strategies. The infiltration rates in the organic-fertilized plots (fym) and combined-fertilized plots

(NPK+fym) were higher compared to the only mineral-fertilized plots (NPK) (Fig. 3.33) (see also Bhattacharyya et al., 2007). The high infiltration rates in the organic and combined-fertilized plots are attributed to the positive modifications of soil properties induced by the effects of farmyard manure (Sharma and Sharma, 1993).

Own results revealed that the higher infiltration rates occurred along with the increase of soil organic carbon content by organic and combined fertilization as compared to mineral fertilization (Fig. 3.33). This is well supported by Kundu et al (2002). In addition, it was clearly found that organic and combined fertilization achieved a lower soil dry bulk density and a higher soil aggregate stability in comparison to mineral fertilization (Fig. 3.35 and Fig. 3.38). The higher soil aggregate stability and the lower soil dry bulk density were related to the higher soil organic carbon content induced by the farmyard manure (Mapa and Gunasena, 1995). As soil structure has a great effect on the soil water infiltration (Conolly, 1998), the improved soil structure (as a high soil mechanical stability and a decreased bulk density) induced by way of the farmyard manure, contributed to increased water infiltration rates of soil. In the plots treated with the farmyard manure, the higher infiltration rates were accompanied by a lower soil penetration resistance and a lower soil dry bulk density compared to the only mineral-fertilized plots (Fig. 3.37). The soil dry bulk density commonly reflects the soil penetration resistance, e.g., the high bulk density results in a high penetration resistance (Cassel, 1982). Thus, since the soil bulk density and the soil penetration resistance are interrelated and used for the estimation of soil strength (Campbell and Henshall, 1991), the use of both together tends to be useful to predict the water infiltration potential of soil. It can be inferred that the soil under the input of farmyard manure can be characterized by a high content of organic carbon, an improved structure, a reduced bulk density, a low strength, and high water infiltration rates.

Although it was well known how organic fertilization influences soil physical and chemical properties, the knowledge of its effect on the soil biological activity is strongly required. The most important variables employed in the present work to assess the soil biological condition are earthworms and the dehydrogenase activity. The estimation of the dehydrogenase activity reflects the general microbial activity of soil (Masciandaro et al., 2004). Own results showed that the soil dehydrogenase activity, as well as earthworm abundance and biomass were greater in the fym-treated plots and the NPK+fym-treated plots than in the NPK-treated plots (Fig. 3.40 and Fig. 3.41). This was related to a greater content of soil organic matter under organic and combined fertilization in comparison to mineral fertilization. This is because earthworm density is positively influenced by the distribution of soil organic matter (Edwards and Bohlen, 1996). Earthworms as decomposers require a permanent supply of different organic materials (Lee, 1985), and hence the larger earthworm populations were related to a higher content of soil organic matter. Tiwari (1993) indicated that earthworm biomass was three times larger in the plots treated with manure compared to the plots treated with inorganic fertilizers, while the plots fertilized with a combination of manure and inorganic fertilizer produced the largest earthworm biomass. Werner and Dindal (1989) stated that the earthworm population (numbers and biomass) was greater under organic fertilization than under inorganic fertilization. In addition, mineral fertilizers could have detrimental impacts on earthworms. For instance, high amounts of ammonium sulphate can produce soil acidification causing a reduction in the earthworm population (Ma et al., 1990).

Also, the dehydrogenase activity is excited by soil organic matter (Liang et al., 2005). This finding was found to be consistent with numerous studies (Tirol-Padre et al., 2007; Edwards et al., 1995; Edwards, 1983).

Thus, soil under farmyard manure can be characterized by a higher biological activity and by a greater number of macro and biopores related to a higher earthworm activity, which help to facilitate water movement producing increased water infiltration abilities into the soil. By understanding the effects of farmyard manure on soil properties, it can be deduced that organic fertilization, by promoting higher soil infiltration rates, provides a precautionary measure to avoid soil loss by flooding-generated erosion.

4.2 The problem of silent sealing of arable soils

Soil sealing is considered one of the main threats to soil together with compaction, organic matter decline, flooding, erosion, soil biodiversity loss, salinization, contamination and landslides (Campbell, 2008).

Soil sealing leads to several serious consequences, in particular increased flood risks.

The problem of soil sealing intensified by inappropriate agronomic managements is qualified as “silent” sealing. It can also be expressed as a loss of the soil infiltration capacity induced by the soil surface sealing or the subsoil sealing (soil compaction).

Surface seals are described as thin crusts, which range in size between segments of one millimeter up to several centimeters (Rogasik et al., 2004). The soil surface sealing takes place due to aggregate breakdown induced by raindrop-energy during rainfall events on the soil surface (Roth and Eggert, 1994). Thus, the breakdown of soil aggregates leads to the soil surface sealing and hence the formation of soil crusts (Bohl and Roth, 1993). It can be deduced that the aggregate disruption at the soil surface, resulting from the strong influence of raindrops on the soil surface, is the basic factor that leads to the surface sealing and the soil crust formation. The crust formation at the soil surface results in a decrease in the hydraulic conductivity of soil (Martens and Frankenberger, 1992). Hence, the soil surface sealing causes reductions of soil infiltration. Shukla and Lal (2006) reported that the formation of a 5-mm thick seal has a strong impact on infiltration and can induce an up to a 75% decrease in the soil infiltration rate. Also, Rogasik et al (2004) revealed that sealed soils have noticeably limited infiltration capacities. As aggregate breakdown is the trigger factor causing the soil surface sealing, the soil aggregate stability, in particular at the surface, should be enhanced in order to avoid the seal formation. This opinion is consistent with several studies. Le Bissonnais (1996) indicated that the lower aggregate stability at the soil surface produced a higher soil susceptibility to the surface sealing. The higher soil aggregate stability is correlated with a higher content of soil organic matter (Chaney and Swift, 1984) and hence, the organic matter content can reduce the formation of soil surface seal (Lado et al., 2004).

The soil aggregate stability is strongly influenced by tillage practices. Intensive soil tillage strategies, including the removal of crop residues from the soil, result in great damage to soil aggregates, producing a loss of mechanical stability (Unger, 1992; Hernanz et al., 2002; Rogasik et al., 2004). The high soil aggregate stability can be achieved under tillage treatments, which guarantee no or minimum soil disturbance and contribute to higher inputs of surface crop residues as a resource of organic matter.

Own results obtained from a long-term field experiment in Braunschweig showed, clearly and precisely, that the higher soil aggregate stability was related to a greater content of soil organic matter under conservation tillage in comparison to conventional tillage (Chapter 3.3). The higher infiltration rate was generated not only by larger numbers of soil macropores and biopores but also by a higher soil resistance to the surface sealing. A simple agronomic method to prevent the extension of surface sealing is the use of appropriate crop rotations, with a maximum duration of soil covering by living plants.

The “silent” soil sealing can occur as well due to compaction of soil below the frequent tillage depth (Jorajuria et al., 1997). It takes place because of the mechanical stress on the soil induced by heavy machinery loads (Etana and Håkansson, 1994), and due to intensive tillage operations (Gaultney et al., 1982). Soil compaction leads to a decrease of soil macropores, an increase of the soil dry bulk density and the penetration resistance and hence causes reductions of water infiltration rates (Hillel, 1982; Oussible et al., 1992; Håkansson and Reeder, 1994; Ishaq et al., 2003). Compacted soils can be characterized by a decreased aggregate stability and thus by a low structural stability.

Own investigations have shown that the land use system is an important measure to guarantee high infiltration rates. The dry bulk density of arable fields was higher compared to natural succession (Table 3.2). This is attributed to the fact that the natural succession soil is not subjected to the mechanical stress by heavy machinery loads, trampling, or field traffic whereas, arable fields are under high mechanical loads induced by tillage operations and other agricultural practices. The greater soil compaction strongly reduced the water infiltration rate of arable fields (Fig. 3.1). Besides, soil compaction causes great damage to the earthworm population (Langmaack, 1999). This is well proved by results of the present work, where natural succession supported a greater earthworm number and biomass, in particular a much higher number of “anecic” earthworms in comparison to the arable fields (Chapter 3.1).

The physical condition of compacted soils is positively influenced by the earthworm activity (Edwards and Bohlen 1996), and thus earthworms can mitigate soil compaction through the burrowing activity and cast production (Whalley et al., 1995). This is proved in the present work, where the results acquired from the differently fertilized plots have been found to sustain the role of earthworms in amelioration of compacted soils. The organic-fertilized plots had a lower dry bulk density and penetration resistance in the deeper soil layer and thus lower soil compaction compared to the mineral-fertilized plots. The lower soil compaction was accompanied by a higher earthworm activity (a larger biomass and abundance, especially with higher numbers of “anecic” earthworms) (Chapter 3.4). Hence, it can be deduced that the earthworm activity contributes to lessening soil sealing.

Finally, it can be concluded that it is immensely important to avoid or minimize the “silent” soil sealing to prevent infiltration losses. This task can be achieved by the sustainable agricultural management. For instance, conservation tillage results in more protection of soil surface against the negative impacts of raindrops. Crop residues on the soil surface protect the soil and in turn contribute to a greater content of organic matter and thus a higher aggregate stability. Moreover, soil compaction could be reduced as a result of a higher earthworm activity and less mechanical loads under conservation tillage.

The investigations have revealed a set of agents, which have positive impacts on infiltration rates. Organically managed soils support the foundation of biopores producing higher infiltration rates than conventionally managed soils. Therefore, organic farming becomes as a very significant procedure to counteract the adverse consequences of the anthropogenic sealing of soils (Schnug and Haneklaus, 2002).

4.3 Evaluation of the infiltration capacity as a soil protection indicator

An indicator system relevant to soil protection should concern the area of water infiltration into the soil profile. The infiltration capacity is defined as the maximum rate of water absorbed by soil (Fares, 2005). The infiltration capacity should be considered as a very essential agent for soil conservation against the water erosion (Kroulík et al., 2007). High infiltration rates of soil are necessary to resupply the water storage capacity and reduce the hazard of temporal flooding of soil during heavy rainfall events. Based on the results discussed in the preceding Chapters 4.1 and 4.2, it can be decided that the infiltration capacity, as a soil property, is significantly associated with important physical, chemical and biological soil properties. Therefore, the infiltration capacity can reflect soil conditions and can be used as a soil quality indicator (Rogasik et al., 2004).

In the present work, the plots of the long-term field experiment, arable land “B”, – a former forest site 60 years ago- are characterized by a higher soil fertility compared to the plots of arable land “A” (“old” arable land), which showed indications of soil degradation caused by an intensive agronomic management for more than 150 years. The following comparison of selected experimental results can help to evaluate the infiltration capacity as an indicator of soil protection (Table 3.24).

Tab. 3.24: Comparison between the properties of non-degraded and degraded soils

Soil properties	Non-degraded soil (Arable land “B”)	Degraded soil (Arable land “A”)
Water infiltration rate	100%	20%
Organic carbon	100%	60%
Aggregate stability	100%	87%
Earthworm abundance	100%	22%

The results listed in Table 3.24 are in agreement with Tian (1998) who revealed that the degraded soil was 88% lower in the water infiltration rate and 38% less in the soil organic carbon content as compared to the non-degraded soil.

The higher infiltration rates measured in the plots of the arable land "B" are accompanied by a higher soil aggregate stability and a higher number of earthworms compared to the plots of the arable land "A". The water infiltration of soil is strongly affected by the soil structure, because the poor soil structure (low aggregation and low porosity) induces a great limitation of water infiltration (Conolly, 1998). Hence, the higher infiltration rate is associated with a higher aggregate stability in the soil (Mapa and Gunasena, 1995). In addition, increased soil infiltration rates are related to a high number of soil macropores (Hillel, 1982; Edwards et al., 1988), and a much larger earthworm population (Bowman, 1993), with an essential impact on the soil structure and porosity.

Finally, it was shown that the higher infiltration rate in the arable land "B" occurred along with a higher soil organic carbon content in comparison to the arable land "A". Organic soil amendments stimulate the biochemical activity, diminish the soil bulk density, and enhance the aggregate stability and the water infiltration rate of the soil (see Martens and Frankenberger, 1992).

It can be summarized that the higher soil fertility found especially in the arable land "B" provides a greater soil protection against soil degradation. Consequently, the higher soil protection is accompanied by higher infiltration rates and hence, it can be concluded that the degree of soil protection can be indicated by the degree of infiltration rate.

Thus, the rate of water infiltration into the soil profile is a relevant indicator of soil protection.

5 Summary

The purpose of this work was to identify factors influencing the infiltration capacity of agricultural lands in order to evaluate "infiltration" as an indicator of soil protection against degradation or water erosion. Long-term field experiments and fields on experimental farms with different land use systems and agricultural management practices were investigated for soil physical, chemical and biological characteristics and their effects on the infiltration capacity. The most important factors affecting infiltration were selected on the basis of the single regression analysis. The different impacts of the selected parameters on infiltration have been identified based on the multiple regression analysis. The soil protection indicator "infiltration" was described according to adequate model algorithms.

1 The investigation of soil infiltration rate under different land use systems produced the following findings:

- The infiltration rate of soil was found to be highest in the forest followed by the natural succession and lowest in the arable land.
- The high infiltration rates in the forest were attributed to higher macropores resulting from the great root activity, which leads also to high lateral fluxes into the soil resulting in higher infiltration rates.
- The higher infiltration rate in the natural succession was due to a higher soil structural stability produced by a higher aggregate stability, which in turn was generated by a greater soil organic matter content. In addition, the natural succession soil had less subsoil compaction and a lower bulk density, besides a higher fraction of biopores mostly produced by larger earthworm abundance, which contributed to increased soil infiltration rates.

2 The investigation of soil infiltration rate under different farming systems yielded the following results:

- Organic farming resulted in higher soil infiltration rates in comparison to conventional farming.
- The higher infiltration rate in the organically managed field (Field O3), as contrasted with the conventionally managed field (Field C1), was traced back to a higher soil mechanical stability, a higher fraction of macro- or biopores (soil pores with a diameter > 50µm) related to the earthworm activity. The earthworm population in Field O3 was twice as greater than in Field C1.

3 The investigation of soil infiltration rate under different soil tillage treatments reported the following consequences:

- The soil infiltration rate was found to be higher under shallow tillage as compared to deep tillage. Also, conservation tillage yielded a higher infiltration rate in comparison to conventional tillage.
- Conservation tillage resulted in a higher aggregate stability, which contributed to a higher soil infiltration rate in comparison to conventional tillage.
- Shallow tillage produced a higher soil biological activity indicated by a larger earthworm population, especially a greater number of deep earthworms “anecic”, and a higher dehydrogenase activity, as well as a higher soil structural stability, which promoted higher infiltration rates compared to deep tillage.

4 The investigation of soil infiltration rate under different fertilization treatments revealed the following effects:

- The infiltration rate was higher under the organic (fym) and the combined (NPK+fym) fertilization than under the mineral fertilization (NPK).
- The organic (fym) and the combined (NPK+fym) fertilization resulted in a higher soil stability, a lower subsoil compaction, a greater organic matter content, a larger earthworm biomass and number particularly a greater number of deep “anecic” earthworms which supported higher soil infiltration rates in comparison to the mineral fertilization (NPK).

5 The multiple regression analysis for the most important factors affecting the water infiltration of soil resulted in the following findings:

- At the site Braunschweig, the carbon stock had the highest influences on the infiltration rate followed by the soil dry bulk density and earthworm abundance.
- At the sites Trenthorst and Mariensee together, the greatest effects on the infiltration rate emerged from the soil textural classes (silt and clay content of the topsoil) followed by the soil dry bulk density and the earthworm abundance per carbon stock, as well as the aggregate stability of the topsoil.

6 The evaluation of the soil infiltration measurements revealed that the infiltration capacity is an adequate integrating measure for soil quality. The improved soil properties

produce a high soil protection against water erosion and simultaneously a high soil infiltration capacity. Hence, the soil infiltration capacity can reflect the level of soil degradation and subsequently it can be used as a fundamental basis for measures of soil protection.

Zusammenfassung

Ziel der Arbeit war es, Einflussfaktoren der Infiltrationskapazität landwirtschaftlicher Böden zu identifizieren, um die „Infiltration“ als Indikator für den Schutz des Bodens gegen Degradation, z.B. Wassererosion, zu bewerten. Dazu wurden Langzeitversuche und Praxisschläge mit unterschiedlicher Landnutzung und Bewirtschaftungsform auf bodenphysikalische, bodenchemische und bodenbiologische Eigenschaften untersucht und deren Einfluss auf die Infiltrationskapazität der Böden quantifiziert. Die wichtigsten Einflussfaktoren für hohe Infiltrationsraten wurden mittels Regressionsanalyse bestimmt. Die unterschiedliche Einflussnahme der ausgewählten Parameter auf die Infiltrationskapazität wurde auf der Basis der multiplen Regressionsanalyse berechnet. Der Bodenschutzindikator "Infiltration" wurde durch abgeleitete Modell-Algorithmen angemessenen beschrieben.

1 Die Untersuchung der Infiltrationsraten bei unterschiedlicher Landnutzung ergab folgende Ergebnisse:

- Die Infiltrationsrate war unter forstwirtschaftlicher Nutzung am höchsten, gefolgt von der natürlichen Sukzession. Auf ackerbaulichen Flächen war sie am geringsten.
- Die hohen Infiltrationsraten bei Waldböden waren das Ergebnis einer größeren Anzahl von Makroporen durch eine intensive Wurzelaktivität, die wiederum zu einem erhöhten lateralen Fluss und somit zu erhöhten Infiltrationsraten führte.
- Bei der natürlichen Sukzession war besonders die verbesserte Strukturstabilität (großer Anteil stabiler Aggregate durch vermehrte organische Bodensubstanz) ausschlaggebend für erhöhte Infiltrationsraten. Zusätzlich war der Unterboden aufgrund der geringeren Trockenrohdichte weniger verdichtet. Hohe Anteile von Bioporen, die zum größten Anteil auf Regenwurmgänge zurückzuführen waren, trugen ebenfalls zu erhöhten Infiltrationsraten bei.

2 Die Untersuchung der Infiltrationsrate für unterschiedliche Bewirtschaftungsformen ergab folgende Ergebnisse:

- Ökologische Landwirtschaft führte zu höheren Infiltrationsraten im Vergleich zu konventioneller Landwirtschaft.
- Die erhöhten Infiltrationsraten des ökologisch bewirtschafteten Feldes (Feld O3) waren im Vergleich zum konventionellen Feld (Feld C1) auf eine verbesserte mechanische Stabilität

des Bodens sowie einen erhöhten Anteil von Makro- bzw. Bioporen (Bodenporen mit einem Durchmesser größer als 50 µm) durch eine hohe Regenwurmaktivität zurückzuführen. Die Regenwurmpopulation des Feldes O3 war doppelt so hoch als im Feld C1.

3 Die Untersuchung der Infiltrationsrate für unterschiedliche Bodenbearbeitungssysteme ergab folgende Ergebnisse:

- Die Infiltration von Wasser in den Boden war höher bei flacher im Vergleich zu tieferer Bodenbearbeitung. Zudem zeigte sich eine höhere Infiltrationsrate bei konservierender verglichen mit konventioneller Bodenbearbeitung.
- Flache bzw. konservierende Bodenbearbeitung führte im Vergleich zu tiefer gepflügten Feldern zu einer höheren bodenbiologischen Aktivität, die sich durch eine erhöhte Anzahl von tief grabenden Regenwürmern (anecic species), eine erhöhte Dehydrogenaseaktivität und eine verbesserte Aggregatstabilität auszeichnet, was im Endeffekt ansteigende Infiltrationsraten garantiert.

4 Die Untersuchung der Infiltrationsrate bei unterschiedlicher Düngungsstrategie ergab folgende Ergebnisse:

- Die Infiltrationsrate war unter organischer (fym) und der kombinierten organisch-mineralischen Düngung (NPK + fym) höher als unter Einsatz von mineralischen Düngemitteln (NPK).
- Organische (fym) und kombiniert organisch-mineralische Düngung (NPK + fym) resultierten in einer erhöhten Aggregatstabilität, geringerer Bodenverdichtung im Unterboden, einer höheren organischen Bodensubstanz, erhöhter Regenwurmbiomasse und insbesondere einer höheren Anzahl von tief grabenden Regenwürmern. Dieses erhöhte die Infiltrationsraten im Vergleich zu nur mineralisch gedüngten Feldern (NPK).

5 Die multiple Regressionsanalyse für die wichtigsten die Wasserinfiltration in den Boden beeinflussenden Faktoren ergab folgende Ergebnisse:

- Auf dem Versuchsstandort Braunschweig hatte der Kohlenstoffvorrat im Boden den größten Einfluss auf die Infiltrationsrate, gefolgt von der Trockenrohdichte und der Regenwurmabundance.

  Auf den Standorten Trendhorst und Mariensee hatten die Bodentextur (Schluff- und Tongehalt des Oberbodens), Trockenrohdichte des Bodens, die Regenwurmanzahl pro Tonne Kohlenstoffvorrat und die Aggregatstabilität des Oberbodens den größten Einfluss.

6 Die Auswertung der Untersuchungen zur Infiltration belegte, dass die Infiltrationskapazität ein adäquates, integrales Maß für die Bewertung der Bodenqualität darstellt. Verbesserte Bodeneigenschaften garantieren einen verbesserten Schutz des Bodens

gegenüber Wassererosion und erhöhen gleichzeitig die Infiltrationskapazität des Bodens. Folglich reflektiert sich in der Infiltrationskapazität das Degradationsniveau des Bodens, welches die Grundlage für Maßnahmen des Bodenschutzes darstellt.

6 References

Angers DA, Mehuys GR (1993) Aggregate stability to water In: Soil sampling and methods of analysis, Carter MR, Ed., Canadian Society of soil science. Lewis Publishers. ISBN 0-87371-861-5.

Ankeny MD, Kaspar TC, Horton R (1990) Characterization of tillage and traffic effects on unconfined infiltration measurements. Soil Sci. Soc. Am. J. **54**: 837–840.

Aubum AL (2001) Agriculture management and earthworm populations. Technical note no11. Soil quality institute. Department of Agriculture,US.

Aura E (1999) Effects of shallow tillage on physical properties of clay soil and growth of spring cereals in dry and moist summers in southern Finland. *Soil Till. Res.* 50, pp. 169–176.

Bhattacharyya R, Chandra S, Singh RD, Kundu S, Srivastva AK, Gupta HS (2007) Long-term farmyard manure application effects on properties of a silty clay loam soil under irrigated wheat–soybean rotation. Soil & Tillage Research 94 386–396.

Bohl H, Roth CH (1993) A simple method to assess the susceptibility of soils to form surface seals under field conditions. Catena 20 pp. 247–256.

Bowman G (1993) Earthworms first! Food and shelter keep these soil builders burrowing under your feet. The New Farm 15, 20-25.

Buczko U, Bens O, Hangen E, Brunotte J, Hüttl RF (2003) Infiltration and macroporosity of a silt loam soil under two contrasting tillage systems. Landbauforschung Völkenrode(53): 181-190.

Buschiazzo DE, Panigatti JL, Unger PW (1998) Tillage effects on soil properties and crop production in the subhumid and semiarid Argentinean Pampas. Soil and Tillage Research, Volume 49, Number 1, pp. 105-116.

Campbell A (2008) Managing Australia's Soils: A Policy Discussion Paper. Prepared for the National Committee on Soil and Terrain (NCST) through the Natural Resource Management Ministerial Council (NRMMC).

Campbell DJ, Henshall JK (1991) Bulk density. *In* K.A. Smith and C.E. Mullins (ed.) Soil analysis. Physical methods. Marcel Dekker, New York. p. 329–366.

Carter MR (1993) Soil sampling and methods of analysis, Ed., Canadian Society of soil science. Lewis Publishers. ISBN 0-87371-861-5.

Carter MR, Ball BC (1993) Soil porosity. In: Soil sampling and methods of analysis, Carter MR, Ed., Canadian Society of soil science. Lewis Publishers. ISBN 0-87371-861-5.

Cassel DK (1982) Tillage effects on soil bulk density and mechanical impedance. *In* P.W. Unger and D.M. Van Doren (ed.) Predicting tillage effects on soil physical properties and processes. ASA Spec. Publ. 44. ASA and SSSA, Madison, WI. p. 45–67.

Chan KY (2001) An overview of some tillage impacts on earthworm population abundance and diversity- implications for functioning in soils. Soil and tillage research, vol.57, issue 4, pp. 179-191.

Chaney K, Swift RS (**1984)** The influence of organic matter on aggregate stability in some British soils. Journal of soil Science.35, 223-230.

Conolly RD (1998) Modelling effects of soil structure on the water balance of soil-crop system: a review. Soil andTillage Research 48: 1-19.

Culley JLB (1993) Density and compressibility. In: Soil sampling and methods of analysis. M.R. Carter. Canadian Society of soil science. Lewis publishers. ISBN 0-87371-861-5.

Curci M, Pizzigallo MDR, Crecchio C, Mininni R, Ruggiero P (1997) Effects of conventional tillage on biochemical properties of soils. Biol Fertil Soils 25:1–6.

Deibert EJ, Utte RA, Schwert DP (1991) Tillage system influence on earthworms (Lumbricidae) in North Dakota. N. Dak. Farm Res. 48, 10-12.

Durner W (1994) Hydraulic conductivity estimation for soils with heterogeneous pore structure, *Water Resour. Res.*, 30(2), 211–223.

Durner W, Lipsius K (2005) Determining Soil Hydraulic Properties. Encyclopedia of Hydrological Sciences, John Wiley & Sons, Ltd.

Durner W (2008) Ringinfiltration. Skript. Institut für Geoökologie, Abteilung Bodenkunde und Bodenphysik, TU Braunschweig, 13 Seiten.

Edwards CA (1983) Earthworm ecology in cultivated soils. In: Satchell, J.E. (ed.). Earthworm Ecology from Darwin to Vermiculture. Chapman and Hall. London. pp.123-138.

Edwards CA, Bohlen PJ (1996) Biology and Ecology of Earthworms, 3rd edn., Chapman and Hall, London, 426 pp.

Edwards CA, Bohlen PJ, Linden DR, Subler S (1995) Earthworms in agroecosystems. In P.F. Hendrix (ed.) Earthworm ecology and biogeography. Lewis, Boca Raton, FL. P. 185-206.

Edwards CA, Lofty JR (1977) Biology of Earthworms, 2nd. ed. Chapman and Hall, London. 333 pp.

Edwards WM, Norton LD, Redmond CE (1988) Characterizing macropores that affect infiltration into nontilled soil. Soil Sci. Soc. Am. J. 52,pp. 483-487.

Edwards WM, Shipitalo MJ, Norton LD (1988) Contribution of macroporosity to infiltration into a continuous corn no-tilled watershed : Implications for contaminant movement. J. Contam. Hydrol. 3:193-205.

Ernest W, Tollner P E (2002) Natural resources engineering. Iowa State Press. United States.0-8138-1847-8.

Etana A, Håkansson I (1994) Swedish experiments on the persistence of subsoil compaction caused by vehicles with high axle load. Soil Till. Res. 29 pp. 167–172.

Fares A (2005) Infiltration, Runoff and stream flow. Watershed Hydrology, NREM 691. UHM-CTAHR-NREM.

Gaultney L, Krutz GW, Steinhardt GC, Liljedahl JB (1982) Effects of subsoil compaction on corn yields, Trans. Am. Soc. Agric. Eng. 25 pp. 563–569.

Håkansson I, Reeder RC (1994) Subsoil compaction by vehicles with high axle load—extent, persistence and crop response. Soil Till. Res. 29 pp. 277–304.

Hangen E, Buczko U, Bens O, Brunotte J, Huttl RF (2002) Infiltration patterns into two soils under conventional and conservation tillage: influence of the spatial distribution of plant root structures and soil animal activity. Soil and Tillage Research, Volume 63, Number 3, pp. 181-186.

Hartge HK (1988) The problem of compaction on agricultural lands. Applied Geography and Development 32. 44-50.

Heermann D, Duke HR (1983) Applications in drylandagriculture. In: Advances in Infiltration. Proc. of NationalConference on Advances in Infiltration. American Society of Agriculture Engineers, St. joseph, MI, pp. 254-263.

Hermawan B, Cameron KC (1993) Structural changes in a silt loam under long-term conventional or minimum tillage. Soil and Tillage Research, 26: 139-150.

Hernanz JL, López R, Navarrete L, Sánchez-Girón V (2002), Long-term effects of tillage systems and rotations on soil structural stability and organic carbon stratification in semiarid central Spain, Soil Till. Res. 66 pp. 129–141.

Hillel D (1980) Fundamentals of Soil Physics. Academic Press Inc., New York, USA.

Hillel D (1982) Introduction to soil physics. Academic Press Inc., New York, USA.

Hoffmann G (1991) VDLUFA- Methodenbuch Band I: Die Untersuchung von Böden. Darmstadt: VDLUFA-Verlag, Loseblattsammlung, ISBN 3-922712-42-8.

Holland JM (2004) The environmental consequences of adopting conservation tillage in Europe: reviewing the evidence. Agriculture Ecosystems and the Environment 103: 1-25.

Hubbard VC, Jordan D, Stecker JA (1999) Earthworm response to rotation and tillage in a Missouri claypan soil. Biol fertile soils 29:343-347.

International Standard (ISO) 23611-1 (2003): Soil quality- Sampling of soil invertebrates-Part 1: Hand-sorting and formaline extraction of earthworms.

International Standard (ISO) 11277 (1998): Soil quality- Determination of particle size distribution in mineral soil material- Method by sieving and sedimentation.

Ishaq M, Ibrahim M, Lal R (2003) Persistence of subsoil compaction effects on soil properties and growth of wheat and cotton in Pakistan. Expl Agric. volume 39, pp. 341–348.

Jorajuria D, Draghi L, Aragon A (1997) The effect of vehicle weight on the distribution of compaction with depth and the yield of Lolium/Trifolium grassland, *Soil Till. Res.* 41, pp. 1–12.

KA 5 (Bodenkundliche Kartieranleitung. 5. Aufl) (2005) Bundesanstalt für Geowissenschaften und Rohstoffe. Schweitzerbart´sche Verlagsbuchhandlung. Stuttgart. S. 438.

Kladivko EJ, Akhouri NM, Weesies G (1997) Earthworm populations and species distribution under no-till and conventional tillage in Indiana and Illinois. Soil Biol. Biochem. Vol. 29. No.3/4, pp. 613-615.

Kladivko EJ, Mackay AD, Bradford JM (1986) Earthworms as a factor in the reduction of soil crusting. Soil Sci. Soc. Am. J. 50:191-196.

König J (1923) Untersuchung landwirtschaftlich und landwirtschaftlich-gewerblich wichtiger Stoffe: Bd. I. Berlin Parey,pp:177-178.

Kouwenhoven JK, Perdok UD, Boer J, Oomen GJM (2002) Soil management by shallow mouldboard ploughing in The Netherlands. Soil and Tillage Research. Volume 65, Issue 2, Pages 125-139.

Kroulík M, Hůla J, Šindelář R, Illek F (2007). Water infiltration into soil related to the soil tillage intensity. Soil and Water Res., 2: 15-24.

Kundu S, Prakash V, Ghosh BN, Singh RD, Srivastva AK (2002) Quantitative relationship between annual carbon inputs and soil organic carbon build-up in soybean (Glycine max)–wheat (Triticum aestivum) cropping sequence, Proceedings of the 2nd International Agron. Congress New Delhi, India, November 26–30 pp. 108–110.

Kutilek M (2004) Soil hydraulic properties as related to soil structure. Soil Till. Res. 79, 175–184.

Lado M, Paz A, Ben-Hur M (2004) Organic matter and aggregate size interactions in infiltration, seal formation, and soil loss. Soil Sci. Soc. Am. J. 68:935-942.

Lal R (1990) Soil erosion in the Tropics: Principles and Management. Mc-Graw-Hill Inc. New York, USA.

Langmaack M (1999) Earthworm communities in arable land influenced by tillage, compaction, and soil. Z. Ökologie u. Naturschutz 8, pp. 11–21.

Le Bissonnais Y, Arrouays D (1997) Aggregate stability and assessment of soil crustability and erodibility:II. Application to humic loamy soils with various organic carbon contents. Eur. J. Soil Sci. 48 : 39-48.

Le Bissonnais Y (1996) Aggregate stability and assessment of soil crusting and erodibility: 1. Theory and methodology. Eur. J. Soil Sci. 47:425–437.

Lee KE (1985) Earthworms: Their Ecology and Relationships with Soils and Land Use. CSIRO, Sydney Australia. 411 pp.

Liang Y, Nikolic M, Peng Y, Chen W, Jiang Y (2005) Organic manure stimulates biological activity and barley growth in soil subject to secondary salinization. Soil Biol. Biochem. 37:1185–1195.

Lipiec J , Kus J, Nosalewicz A, Turski M (**2006**) Tillage system effects on stability and sorptivity of soil aggregates. Int. Agrophysics, , 20, 189-193.

Logsdon SD, Allmaras RR, Wu L, Swan JB, Randall GW (1990) Macroporosity and its relation to saturated hydraulic conductivity under different tillage practices. Soil Sci. Soc. J. 54: 1096-1101.

Ma WC, Brussaard L, et De Ridder JA (1990) Long-term effects of nitrogenous fertilizers on grassland earthworms (*Oligochaeta: Lumbricidae*): Their relation to soil acidification. Agr. Ecosyst. Environ. 30: 71–80.

Mackay AD, Kladivko EJ (1985) Earthworms and rate of breakdown of soybean and maize residues in soil. Soil Biol. Biochem. 17(6):851-857.

Madeira MVA, Melo MG, Alexandre CA, Steen E (1989) Effects of deep ploughing and superficial disc harrowing on physical and chemical soil properties and biomass in a new plantation of *Eucalyptus globulus. Soil Tillage Res.,* 14: 163-175.

Malkomes HP (1991) Vergleich der TTC- und INT-Reduktion zum Nachweis von Pflanzenschutzmittelwirkungen auf die Dehydrogenaseaktivität im Boden. Nachrichtenbl Dtsch Pflanzenschutzd 43: 52–57.

Mann L, Tolbert V (2000) Soil Sustainability in Renewable Biomass Plantings. AMBIO: A Journal of the Human Environment. Volume 29. Issue 8. Article: pp. 492–498.

Mapa RB (1995) Effect of reforestation using *Tectona grandis* on infiltration and soil water retention. Forest Ecology and Management 77 (1995) 119-125.

Mapa RB, Gunasena HPM (1995) Effect of alley cropping on soil aggregate stability of a tropical Alfisol. Kluwer Academic Publishers. Printed in the Netherlands. Agroforestry Systems 32: 237-245.

Martens DA, Frankenberger WT (1992) Modification of infiltration rates in an organic-amended irrigated soil. Agron. J. 84: 707-717.

Masciandaro G, Ceccanti B, Benedicto S,. Lee HC, Cook F (2004) Enzyme activity and C and N stocks in soil following application of mulches. Can. J. Soil Sci. 84:19–30.

Oades JM (1993) The role of biology in the formation, stabilization and degradation of soil structure, *Geoderma* 56 pp. 377–400.

Oussible M, Crookston PK, Larson WE (1992) Subsurface compaction reduces the root and shoot growth and grain yield of wheat. Agronomy Journal 84:34–38.

Pelegrin F, Moreno F, Martin-Aranda J, Camps M, (1990) The influence of tillage methods on soil physical properties and water balance for a typical crop rotation in SW Spain, *Soil Till. Res.* 16 pp. 345–358.

Perucci P (1990) Effect of the addition of municipal solid-waste compost on microbial biomass and enzyme activities in soil. Biol Fertil Soils 10:221–226.

Poudel DD, Ferris H, Klonsky H, Horwath WR, Scow KM, Van Brugen AHC, Lanini WT, Mitchell JP, Temple SR (2001) The sustainable agriculture farming system project in California,s Sacramento vally. Outlook on Agriculture, 30: 159-160.

Ramsay JA, Hill S (1978) Earthworms the agriculturalist's friends. EAP Publication-6. Macdonald Journal. 39(10), 6-8.

Rogasik J, Panten K, Schnug E, Rogasik H (2004) Infiltration Management Factors. Encyclopedia of Soil Science DOI:10.1081 /E-ESS-120019048.

Roth CH, Eggert T (1994) Mechanisms of aggregate breakdown involved in surface sealing, runoff generation and sediment concentration on loess soils. Soil and Tillage

Research 32 253-268.

Schmidt O, Clements RO, Donaldson G (2003) Why do cereal-legume intercrops support large earthworm populations? Soil ecology,vol 22,issue 2, pp.181-190.

Schnug E, Haneklaus S (2002) Agricultural production techniques and infiltration significance of organic farming for preventive flood protection. Landbauforshung Volkenrode 52: 197-203.

Schnug E, Rogasik J, Panten K, Paulsen HM and Haneklaus S (2004) Oekologischer Landbau erhoeht die Versickerungsleistung von Boeden – ein unverzichtbarer Beitrag zum vorbeugenden Hochwasserschutz. Oekologie & Landbau 32 (132): 53-55.

Schrader S, Joschko M, Kula H, Larink O (1995) Earthworm effects on soil structure with emphasis on soil stability and soil water movement. In Soil structure – Its development and function. Lewis Publishers., p 109-133.

Schüller H (1969) Die CAL-Methode, eine neue Methode zur Bestimmung des Pflanzenverfügbaren Phosphats im Boden. Zeitschrift für Pflanzenernährung und Bodenkunde 123: 48-63.

Schwärzel K, Punzel J (2007) Hood Infiltrometer. A new type of tension infiltrometer. Soil Sci Soc. Am 71:1438-1447.

Shainberg I, Levy GJ (1995) Infiltration and Seal Formation Processes.In: Soil Erosion, Conservation and Rehabilitation. Agassi M. United states of America:Marcel Dekker, Inc, 402 p, 0-8247-8984-9. pp 1 – 20.

Sharma GD, Sharma HL (1993) Fertility management for yield maximization of rice–wheat cropping system, Fertil. News 38 pp. 19–23.

Shipitalo MJ, Dick WA, Edwards WM (2000) Conservation tillage and macropore factors that affect water movement and the fate of chemicals. Soil and Tillage Research, Volume53,Issues3-4,pp167-183.

Shukla MK, Lal R (2006) Water Infiltration in Soil. The Ohio State University, Columbus, Ohio, U.S.A. Encyclopedia of Soil Science DOI: 10.1081/E-ESS- 120006659.

Smettem KRJ, Oliver YM, Heng LK, Bristow KL, Ford EJ (1999) Obtaining soil hydraulic properties for water balance and leaching models from survey data. 1. water retention. Australian Journal of Agricultural Research, 50, 283-289.

Sparovek G, van Lier QD,Marciniconis S,Rogasic J,Schnug E (2002) A simple model to predict river floods-a contribution towards quantifying the significant of soil infiltration rates. Landbauforschung Völkenrode (52):187-194.

Statistisches Bundesamt (2008) Nachhaltige Entwicklung in Deutschland. Indikatorenbericht.

Thalmann A (1968) Zur Methodik der Bestimmung der Dehydrogenaseaktivität im Boden mittels Triphenyltetrazoliumchlorid (TTC). Landwirtsch Forsch 21: 249–258.

Tebrügge F, Düring RA (1999) Reducing tillage intensity- a review of results from a long-term study in Germany. Soil and Tillage Research 53: 15-28.

Tian G (1998) Effect of soil degradation on leaf decomposition and nutrient release under humid tropical conditions1. Soil Science 163(11):897-906.

Tirol-Padre A, Ladha JK, Regmi AP, Bhandari AL, Inubushi K (2007) Organic Amendments Affect Soil Parameters in Two Long-Term Rice-Wheat Experiments. Soil Sci Soc Am J 71:442-452.

Tisdall JM, Oades JM (1980) The effect of crop rotation on aggregation in a red-brown earth. Aust. J. Soil Res. 18:423–434.

Tiwari SC (1993) Effects of organic manure and NPK fertilization on earthworm activity in an Oxisol. Biol Fertil Soils 16 : 293–295.

Topp GC (1993) Soil water content**.** In: Soil sampling and methods of analysis, Carter MR, Ed., Canadian Society of soil science. Lewis Publishers. ISBN 0-87371-861-5.

Unger PW (2002) Water conservation in soil. United State Department of Agriculture. Texas:Dekker, Inc. 1384-1386.

Unger PW (1992) Infiltration of simulated rainfall: Tillage system and crop residue effects. Soil Sci. Soc. Am. J. 56: 283-289.

Umwelt-Geräte-Technik (UGT) (2004): Hood Infiltrometer. Müncheberg, Germany

Werner MR (1990) Earthworm ecology and sustainable agriculture. University of California, Santa Cruz, CA95064. Vol. 1, no 4.

Werner MR, Dindal DL (1989) Earthworm community dynamics in conventional and low-input agroecosystems. Revue de Ecologie et Biologie du Soil 26, pp. 427–437.

Whalley WR, Dumitru E, Dexter AR (1995) Biological effects of soil compaction. Soil Till. Res. 35, pp. 53–68.

Wienhold BJ, Tanaka DL (2000) Haying, tillage, and nitrogen fertilization influences on infiltration rates at a conservation reserve program site. Soil Science Society of America Journal 64:379-381.

Wright SF, Starr JL, Paltineanu IC (1999) Changes in aggregate stability and concentration of glomalin during tillage management transition. Soil Sci. Soc. Am. J. 63: 1825–1829.

Wuest SB (2001) Earthworm, infiltration, and tillage relationships in a dryland pea–wheat rotation. Applied Soil Ecology 18 187–192.

Zachmann JE, Linden DR (1989) Earthworm effects on corn residue breakdown and Infiltration. Soil Sci. Soc. Am. 53(6):1846-1849.

Zachmann JE, Linden DR, Clapp CE (1987) Mcroporous infiltration and redistribution as affected by earthworms, tillage, and residue. Soil Sci. Soc. Am. J. 51: 1580-1586.

7 Appendix

Tab. A.1: Soil texture analysis for the studied fields

Site	Field	Plot	Depth (cm)	Sand (%)	Silt (%)	Clay (%)	Soil texture
Braunschweig	36	4	0-30	37.28	55.52	7.2	sandiger Schluff
Braunschweig	36	4	0-30	34.59	58.12	7.28	sandiger Schluff
Braunschweig	36	4	0-30	36.47	56.32	7.21	sandiger Schluff
Braunschweig	36	4	0-30	36.65	56.53	6.81	sandiger Schluff
Braunschweig	36	4	30-60	50.85	42.97	6.18	stark schluffiger Sand
Braunschweig	36	4	30-60	51.97	42.32	5.71	stark schluffiger Sand
Braunschweig	36	4	30-60	53.16	41.51	5.33	stark schluffiger Sand
Braunschweig	36	4	30-60	45.57	48.08	6.34	stark schluffiger Sand
Braunschweig	36	10	0-30	37.01	54.94	8.06	sandiger Schluff
Braunschweig	36	10	0-30	36.22	56.19	7.61	sandiger Schluff
Braunschweig	36	10	0-30	38.07	54.75	7.16	sandiger Schluff
Braunschweig	36	10	0-30	38.05	54.46	7.5	sandiger Schluff
Braunschweig	36	10	30-60	51.25	42.29	6.47	stark schluffiger Sand
Braunschweig	36	10	30-60	36.36	57.06	6.59	sandiger Schluff
Braunschweig	36	10	30-60	37.83	55.3	6.87	sandiger Schluff
Braunschweig	36	10	30-60	38.91	54.16	6.94	sandiger Schluff
Braunschweig	36	12	0-30	37.23	55.09	7.69	sandiger Schluff
Braunschweig	36	12	0-30	37.69	54.54	7.8	sandiger Schluff
Braunschweig	36	12	0-30	37.69	55.22	7.1	sandiger Schluff
Braunschweig	36	12	0-30	37.03	55.24	7.73	sandiger Schluff
Braunschweig	36	12	30-60	50.23	44.09	5.68	stark schluffiger Sand
Braunschweig	36	12	30-60	55.98	38.22	5.8	mittel schluffiger Sand
Braunschweig	36	12	30-60	51.06	43.36	5.59	stark schluffiger Sand
Braunschweig	36	12	30-60	52.75	40.49	6.76	stark schluffiger Sand
Braunschweig	4	1.3	0-30	36.23	57.11	6.65	sandiger Schluff
Braunschweig	4	1.3	0-30	35.75	58.07	6.18	sandiger Schluff
Braunschweig	4	1.3	0-30	32.08	60.55	7.36	sandiger Schluff
Braunschweig	4	1.3	30-60	46.33	48.19	5.48	stark schluffiger Sand
Braunschweig	4	1.3	30-60	62.96	32.5	4.54	mittel schluffiger Sand
Braunschweig	4	1.3	30-60	44.27	49.48	6.26	stark schluffiger Sand
Braunschweig	4	2.3	0-30	36.97	56.43	6.58	sandiger Schluff
Braunschweig	4	2.3	0-30	33.29	59.71	6.99	sandiger Schluff
Braunschweig	4	2.3	0-30	33.93	58.84	7.21	sandiger Schluff
Braunschweig	4	2.3	30-60	63.7	32.33	4.08	mittel schluffiger Sand
Braunschweig	4	2.3	30-60	54.13	41.85	4.03	stark schluffiger Sand
Braunschweig	4	2.3	30-60	48.54	45.87	5.58	stark schluffiger Sand
Braunschweig	4	Succession	0-30	37.96	55.33	6.7	sandiger Schluff
Braunschweig	4	Succession	0-30	34.61	58.45	6.95	sandiger Schluff
Braunschweig	4	Succession	0-30	34.23	58.12	7.65	sandiger Schluff
Braunschweig	4	Succession	30-60	52.1	41.71	6.2	stark schluffiger Sand
Braunschweig	4	Succession	30-60	47.67	45.41	6.91	stark schluffiger Sand
Braunschweig	4	Succession	30-60	39.89	53.04	7.07	sandiger Schluff

Tab. A.1 continued

Site	Field	Plot	Depth (cm)	Sand (%)	Silt (%)	Clay (%)	Soil texture
Braunschweig	Forest	64	0-8	44.3	45.0	10.8	schluffig lehmiger Sand
Braunschweig	Forest	65	10-16	50.4	39.9	9.7	schluffig lehmiger Sand
Braunschweig	Forest	66	18-24	49.4	40.6	10.0	schluffig lehmiger Sand
Braunschweig	Forest	67	26-32	49.8	41.3	8.9	schluffig lehmiger Sand
Braunschweig	Forest	68	34-40	50.7	42.0	7.3	stark schluffiger Sand
Braunschweig	7	1	0-8	39.3	50.5	10.1	sandig lehmiger Schluff
Braunschweig	7	1	10-16	40.2	51.8	7.9	sandiger Schluff
Braunschweig	7	1	18-24	38.3	55.1	6.6	sandiger Schluff
Braunschweig	7	1	26-32	32.6	62.3	5.1	sandiger Schluff
Braunschweig	7	23	0-8	40.6	51.7	7.7	sandiger Schluff
Braunschweig	7	23	10-16	40.4	52.6	7.0	sandiger Schluff
Braunschweig	7	23	18-24	40.5	51.8	7.6	sandiger Schluff
Braunschweig	7	23	26-32	39.5	54.8	5.7	sandiger Schluff
Braunschweig	7	30	0-8	39.4	53.9	6.7	sandiger Schluff
Braunschweig	7	30	10-16	40.0	52.3	7.6	sandiger Schluff
Braunschweig	7	30	18-24	39.3	54.0	6.7	sandiger Schluff
Braunschweig	7	30	26-32	39.6	52.8	7.6	sandiger Schluff
Braunschweig	7	32	0-8	41.7	49.7	8.6	schluffig lehmiger Sand
Braunschweig	7	32	10-16	41.7	51.3	7.0	sandiger Schluff
Braunschweig	7	32	18-24	42.0	51.3	6.7	sandiger Schluff
Braunschweig	7	32	26-32	40.3	54.7	5.1	sandiger Schluff
Braunschweig	10	A	0-24	41.9	50.5	7.6	sandiger Schluff
Braunschweig	10	A	26-48	42.0	51.1	6.9	sandiger Schluff
Braunschweig	10	B	0-24	42.4	51.4	6.2	sandiger Schluff
Braunschweig	10	B	26-48	44.2	48.2	7.6	stark schluffiger Sand
Trenthorst	8	F/8	2-8	39.2	42.1	18.7	schwach sandiger Lehm
Trenthorst	8	F/8	10-16	40.0	41.2	18.7	schwach sandiger Lehm
Trenthorst	8	F/8	18-24	39.4	41.2	19.4	schwach sandiger Lehm
Trenthorst	8	F/8	26-32	39.8	43.4	16.8	schluffig lehmiger Sand
Trenthorst	11	F/11	2-8	45.4	43.5	11.1	schluffig lehmiger Sand
Trenthorst	11	F/11	10-16	45.7	41.4	12.8	schluffig lehmiger Sand
Trenthorst	11	F/11	18-24	45.9	43.4	10.7	schluffig lehmiger Sand
Trenthorst	11	F/11	26-32	45.8	42.3	11.9	schluffig lehmiger Sand
Trenthorst	29	F/29	2-8	43.6	36.8	19.6	mittel sandiger Lehm
Trenthorst	29	F/29	10-16	49.2	34.9	15.9	stark lehmiger Sand
Trenthorst	29	F/29	18-24	48.5	36.0	15.5	stark lehmiger Sand
Trenthorst	29	F/29	26-32	48.9	34.4	16.7	stark lehmiger Sand
Trenthorst	51	F/51	2-8	39.0	42.0	19.0	schwach sandiger Lehm
Trenthorst	51	F/51	10-16	39.3	41.0	19.7	schwach sandiger Lehm
Trenthorst	51	F/51	18-24	39.1	40.2	20.7	schwach sandiger Lehm
Trenthorst	51	F/51	26-32	39.6	41.7	18.7	schwach sandiger Lehm

Tab. A.1 continued

Site	Field	Plot	Depth (cm)	Sand (%)	Silt (%)	Clay (%)	Soil texture
Mariensee	Moorkamp	1	0-15	49.0	43.1	7.9	stark schluffiger Sand
Mariensee	Moorkamp	2	15-30	52.0	37.8	10.2	mittel lehmiger Sand
Mariensee	Moorkamp	3	30-60	52.9	42.0	5.1	stark schluffiger Sand
Mariensee	Fuchsberg	9	0-15	65.3	29.6	5.1	mittel schluffiger Sand
Mariensee	Fuchsberg	10	15-30	68.6	25.0	6.4	mittel schluffiger Sand
Mariensee	Fuchsberg	11	30-60	92.7	2.3	5.0	schwach toniger Sand
Mariensee	Schlag 1 deep	32	0-15	27.5	49.9	22.6	schwach sandiger Lehm
Mariensee	Schlag 1 deep	33	15-30	27.6	48.5	23.9	schwach sandiger Lehm
Mariensee	Schlag 1 deep	34	30-60	33.9	45.5	20.6	schwach sandiger Lehm
Mariensee	Schlag 1 shallow	35	0-15	28.4	49.4	22.2	schwach sandiger Lehm
Mariensee	Schlag 1 shallow	36	15-30	28.2	49.1	22.7	schwach sandiger Lehm
Mariensee	Schlag 1 shallow	37	30-60	28.8	49.3	21.9	schwach sandiger Lehm
Mariensee	Grass	38	0-15	11.4	57.8	30.8	mittel schluffiger Ton
Mariensee	Grass	39	0-30	10.8	59.6	29.6	schluffiger Lehm
Mariensee	Grass	40	30-60	9.5	59.3	31.2	mittel schluffiger Ton
Mariensee	Succession	41	0-15	57.2	37.6	5.2	mittel schluffiger Sand
Mariensee	Succession	42	15-30	57.8	35.7	6.4	mittel schluffiger Sand
Mariensee	Succession	43	30-60	63.7	31.3	5.1	mittel schluffiger Sand

Tab. A.2: Soil chemical analysis for the studied fields

Field	Depth cm	C %	N %	pH	P mg.kg^{-1}	K mg.kg^{-1}	Mg mg.kg^{-1}
BRAUNSCHWEIG	2-8	0.66	0.080	5.99	91.9	178.8	60.3
FV 10	10-16	0.78	0.080	6.31	76.3	169.0	50.2
A	18-24	0.81	0.079	6.31	71.2	169.2	47.3
	26-32	0.77	0.075	6.30	72.5	173.8	48.9
	34-40	0.46	0.047	6.42	42.4	131.6	40.3
	42-48	0.28	0.032	6.54	13.1	93.6	39.5
B	2-8	0.89	0.091	6.05	94.9	113.4	60.9
	10-16	0.99	0.085	6.32	76.3	115.6	60.9
	18-24	0.98	0.085	6.38	75.4	99.4	59.9
	26-32	0.89	0.083	6.40	71.6	109.8	57.3
	34-40	0.43	0.045	6.58	43.6	109.6	50.4
	42-48	0.29	0.029	6.67	18.2	92.0	67.0
FV/4	2-8	1.34	0.096	5.33	53.6	149.6	65.6
1.3	12-16	1.26	0.077	5.36	41.1	98.4	52.8
	20-24	0.52	0.058	5.08	12.5	70.2	34.3
	28-32	0.17	0.036	5.02	6.8	60.2	30.4
2.3	2-8	1.26	0.080	5.26	31.4	87.6	49.5
	12-16	1.25	0.169	5.44	41.5	100.2	51.8
	20-24	0.75	0.040	5.40	12.9	83.6	37.7
	28-32	0.35	0.019	5.24	11.4	56.2	25.8
FV4 PG/Succession	2-8	1.39	0.098	4.62	14.7	109.8	31.1
	10-16	1.25	0.094	4.69	11.0	30.4	24.6
	18-24	1.06	0.070	4.81	13.2	11.8	18.1
	26-32	0.86	0.060	4.94	11.7	9.2	15.6
	34-40	0.48	0.032	4.75	6.3	26.8	16.9
FV/7	2-8	0.68	0.080	5.92	111.8	103.8	54.2
PG1	10-16	0.79	0.077	6.01	83.7	75.0	47.5
	18-24	0.56	0.065	5.87	76.2	63.2	50.2
	26-32	0.38	0.034	5.91	51.8	54.4	39.7

Tab. A.2 continued

Field	**Depth**	**C**	N	**pH**	**P**	**K**	**Mg**
	cm	**%**	**%**		**mg.kg^{-1}**	**mg.kg^{-1}**	**mg.kg^{-1}**
PG23	2-8	1.17	0.098	6.30	117.7	159.6	75.0
	10-16	0.86	0.091	6.04	84.3	135.2	64.5
	18-24	0.63	0.074	5.73	61.0	101.6	57.3
	26-32	0.82	0.075	5.74	62.1	99.2	61.1
PG30	2-8	0.75	0.079	5.19	74.5	98.6	51.5
	10-16	0.79	0.074	5.62	81.0	95.4	60.7
	18-24	0.83	0.076	5.36	85.3	129.6	50.4
	26-32	0.72	0.069	5.42	70.2	107.2	48.9
PG32	2-8	0.80	0.079	5.79	72.9	59.6	58.4
	10-16	0.85	0.081	5.24	74.5	107.8	54.0
	18-24	0.88	0.079	5.58	76.7	136.8	52.7
	26-32	0.86	0.080	5.63	67.0	155.8	91.8
FV36	2-8	1.33	0.102	5.47	53.6	295.2	35.3
FV36 PG 4 (1)	10-16	1.33	0.085	5.44	47.5	76.4	43.2
	18-24	1.43	0.088	5.34	51.8	64.8	41.7
	26-32	1.43	0.091	5.40	52.1	62.6	51.6
	34-40	1.31	0.079	5.25	42.6	38.4	40.1
FV36 PG 4 (2)	2-8	1.16	0.070	5.19	44.5	146.6	28.7
	10-16	1.31	0.080	5.37	54.2	69.0	34.5
	18-24	1.22	0.069	5.51	52.9	104.2	38.8
	26-32	1.30	0.074	5.61	47.7	92.0	42.8
	34-40	1.32	0.079	5.51	56.2	89.6	42.6
FV36 PG 4 (3)	2-8	1.40	0.089	5.41	54.0	143.0	36.2
	10-16	1.52	0.092	5.37	64.4	90.8	43.2
	18-24	1.52	0.086	5.40	57.0	121.6	46.0
	26-32	1.33	0.076	5.42	49.9	101.0	57.4
	34-40	1.02	0.052	5.37	23.1	70.0	36.8

Tab. A.2 continued

Field	Depth cm	C %	N %	pH	P mg.kg^{-1}	K mg.kg^{-1}	Mg mg.kg^{-1}
FV36 PG 4 (4)	2-8	1.27	0.084	5.64	51.4	228.8	39.7
	10-16	1.48	0.087	5.62	54.2	99.2	45.9
	18-24	1.25	0.076	5.51	48.2	92.2	43.2
	26-32	1.38	0.081	5.53	49.0	87.2	42.2
	34-40	0.90	0.051	5.27	28.1	85.4	39.7
FV36 PG 10 (1)	2-8	1.43	0.088	5.82	51.8	229.2	50.4
	10-16	1.56	0.104	5.72	66.3	224.0	128.3
	18-24	1.49	0.096	5.71	62.4	134.4	80.3
	26-32	1.43	0.096	5.59	59.8	126.0	55.0
	34-40	1.22	0.076	5.56	58.8	126.6	51.2
FV36 PG 10 (2)	2-8	1.48	0.097	6.19	84.5	346.4	87.3
	10-16	1.54	0.102	5.79	70.6	245.6	62.8
	18-24	1.56	0.106	6.01	87.7	270.6	77.6
	26-32	1.50	0.097	6.01	84.5	318.2	70.8
	34-40	1.42	0.102	6.19	97.9	458.0	68.4
FV36 PG 10 (3)	2-8	1.19	0.072	5.79	54.2	252.2	52.7
	10-16	1.43	0.088	5.71	68.1	142.8	62.0
	18-24	1.43	0.094	5.72	70.6	117.8	53.7
	26-32	1.65	0.107	5.79	78.0	121.8	56.2
	34-40	1.35	0.081	5.89	71.3	139.6	52.9
FV36 PG 10 (4)	2-8	1.41	0.089	5.88	64.8	223.4	49.2
	10-16	1.45	0.094	5.69	67.2	149.8	50.3
	18-24	1.63	0.103	5.70	67.6	189.8	51.0
	26-32	1.47	0.097	5.82	68.3	211.6	51.5
	34-40	1.11	0.070	5.73	40.4	140.6	47.9
FV36 PG 12 (1)	2-8	1.49	0.068	5.70	199.5	177.4	NA
	10-16	1.48	0.087	5.81	220.2	184	NA
	18-24	1.41	0.080	5.81	227.9	192.2	NA
	26-32	1.44	0.088	5.86	214.4	195.8	NA
	34-40	1.34	0.080	6.08	225.5	316.8	NA

Tab. A.2 continued

Field	Depth	C	N	pH	P	K	Mg
	cm	%	%		$mg.kg^{-1}$	$mg.kg^{-1}$	$mg.kg^{-1}$
FV36 PG 12 (2)	2-8	1.26	0.075	5.71	188.5	173.4	NA
	10-16	1.48	0.088	5.80	220.7	189.8	NA
	18-24	1.38	0.083	5.89	221.6	190.6	NA
	26-32	1.36	0.086	5.88	220.2	203.2	NA
	34-40	1.5	0.091	6.16	225.5	312.8	NA
FV36 PG 12 (3)	2-8	1.41	0.086	5.82	219.7	189.2	NA
	10-16	1.34	0.084	6.01	168.3	135.6	NA
	18-24	1.35	0.082	5.81	208.2	213.8	NA
	26-32	1.46	0.089	6.04	231.3	268	NA
	34-40	1.5	0.089	5.90	200.5	220.8	NA
FV36 PG 12 (4)	2-8	1.46	0.089	5.84	223.6	189.2	NA
	10-16	1.33	0.079	5.80	175.5	146.4	NA
	18-24	1.36	0.078	6.01	204.8	207.2	NA
	26-32	1.37	0.084	6.15	232.2	262.6	NA
	34-40	1.3	0.077	5.92	213.9	222.8	NA
Forest	2-8	4.65	0.282	3.30	127.0	73.8	31.5
	10-16	0.93	0.058	3.59	39.5	7.6	12.2
	18-24	1.48	0.090	3.56	51.6	16.4	12.9
	26-32	0.78	0.057	3.65	29.2	2.0	11.0
	34-40	0.57	0.046	3.69	35.6	0.0	8.6
TRENTHORST	2-8	1.35	0.113	6.56	82.2	97.6	128.5
FV/8	10-16	1.36	0.126	6.62	91.9	153.8	128.1
	18-24	1.55	0.134	6.34	76.7	190.2	136.3
	26-32	1.29	0.118	6.68	89.8	128.4	124.3
FV/11	2-8	1.06	0.099	6.26	64.6	130.2	90.9
	10-16	1.21	0.102	6.14	59.3	138.8	88.4
	18-24	1.07	0.088	6.21	61.2	137.0	85.3
	26-32	1.13	0.098	6.34	64.6	149.4	94.5

Tab. A.2 continued

Field	Depth	C	N	pH	P	K	Mg
	cm	%	%		$mg.kg^{-1}$	$mg.kg^{-1}$	$mg.kg^{-1}$
FV/29	2-8	4.54	0.206	5.54	237.7	299.2	311.4
	10-16	3.50	0.150	5.56	195.3	190.2	238.4
	18-24	1.73	0.095	5.83	120.3	126.2	221.6
	26-32	1.31	0.057	5.90	79.7	128.4	201.0
FV/51	2-8	1.61	0.093	6.54	35.2	132.8	132.7
	10-16	1.64	0.071	6.52	32.8	140.2	137.8
	18-24	1.50	0.066	6.47	33.7	149.4	134.8
	26-32	1.54	0.065	6.46	31.8	150.8	137.1
MARIENSEE	0-15	1.27	0.125	6.45	44.3	133.2	94.9
FV 1 PG: shallow	15-30	1.21	0.127	6.73	45.6	75.2	82.5
	30-60	0.98	0.097	6.88	34.4	51.4	86.7
FV 1 PG: deep	0-15	1.31	0.130	6.10	29.8	107.0	115.3
	15-30	1.24	0.122	6.40	31.1	60.4	89.0
	30-60	0.87	0.090	6.66	23.5	39.8	85.7
MA Grass	0-15	5.07	0.550	5.38	70.4	356.0	236.3
	15-30	2.98	0.322	5.25	43.0	221.4	214.1
	30-60	3.09	0.347	5.45	33.5	164.2	208.1
MA Sucession	0-15	2.32	0.140	5.66	61.8	119.4	55.3
	15-30	1.76	0.106	5.75	54.2	69.0	43.0
	30-60	0.77	0.044	6.01	21.2	27.8	36.7
MA Moorkamp	0-15	4.02	0.194	5.25	54.0	97.6	54.3
	15-30	3.68	0.176	5.32	49.0	182.2	60.1
	30-60	0.70	0.027	5.48	11.2	31.4	17.9
MA Fuchsberg	0-15	1.43	0.124	5.49	82.3	71.4	44.2
	15-30	1.19	0.098	5.62	78.9	97.6	45.1
	30-60	0.09	0.011	5.40	22.0	12.2	13.4

Tab. A.3: Earthworm populations for the studied fields

Field	Abundance	Juvenile	Adult	Epigeic	Endogeic	Anecic	Biomass
	worms m^{-2}			**worms m^{-2}**			**gm^{-2}**
Braunschweig F 36/ 4A	50	34	16	15	29	6	24.68
Braunschweig F 36/ 4B	54	31	23	21	28	5	28.80
Braunschweig F 36/ 4C	47	26	21	17	24	6	27.47
Braunschweig F 36/ 4D	49	28	21	17	25	7	27.16
Braunschweig F 36/ 10A	61	31	30	17	30	14	38.03
Braunschweig F 36/ 10B	66	32	34	15	38	13	39.39
Braunschweig F 36/ 10C	59	22	37	13	37	9	39.08
Braunschweig F 36/ 10D	69	39	30	14	44	11	40.66
Braunschweig F 36/12 A	52	36	16	4	32	16	42.56
Braunschweig F 36/ 12 B	60	40	20	5	43	12	40.04
Braunschweig F 36/12 C	64	40	24	8	44	12	40.52
Braunschweig F 36/12 D	64	32	32	9	40	15	42
Braunschweig 10-A	11	6	5	2	8	1	5.33
Braunschweig 10-B	17	7	10	3	12	2	9.72
Braunschweig Succession	76	34	42	12	53	11	50.95
Braunschweig Forest	0		–	–	–	–	–
Trenthorst FV8	134	77	57	16	97	21	73.57
Trenthorst FV11	88	45	43	8	58	22	89.62
Trenthorst FV29	96	64	32	6	50	40	102.92
Trenthorst FV 51	65	48	17	17	30	18	29.78
Mariensee Schlag1 shallow	166	130	36	43	111	12	49.64
Mariensee Schlag1 deep	92	73	19	20	68	4	25.16
Mariensee F/ Grass	131	44	87	11	101	19	109.63
Mariensee F/succession	89	52	37	15	68	6	26.49

Tab. A.4: Dehydrogenase activity for the studied fields

Field		$\mu gTPFg^{-1}.d^{-1}$	Mean
Braunschweig	**F 36/10A**	37.5	38.1
Braunschweig	**F 36/10B**	36.8	
Braunschweig	**F 36/10C**	40.1	
Braunschweig	**F 36/10D**	38.0	
Braunschweig	**F 36/ 12 A**	30.7	30.7
Braunschweig	**F 36/ 12 B**	26.5	
Braunschweig	**F 36/ 12 C**	36.1	
Braunschweig	**F 36/ 12 D**	29.4	
Braunschweig	**F 36/4A**	25.8	27.8
Braunschweig	**F 36/4B**	28.3	
Braunschweig	**F 36/4C**	29.1	
Braunschweig	**F 36/4D**	28.0	
Braunschweig	**F/10-A**	37.3	29.2
Braunschweig	**F/10-A**	24.9	
Braunschweig	**F/10-A**	27.1	
Braunschweig	**F/10-A**	27.5	
Braunschweig	**F/10-B**	28.2	29.2
Braunschweig	**F/10-B**	25.6	
Braunschweig	**F/10-B**	31.2	
Braunschweig	**F/10-B**	31.8	
Braunschweig	**Succession**	64.7	66.3
Braunschweig	**Succession**	70.1	
Braunschweig	**Succession**	68.6	
Braunschweig	**Succession**	61.8	
Braunschweig	**Forest**	2.6	3.4
Braunschweig	**Forest**	4.1	
Braunschweig	**Forest**	4.0	
Braunschweig	**Forest**	2.8	
Trenthorst F/ 8		8.4	8.77
Trenthorst F/ 8		10.1	
Trenthorst F/ 8		8.2	
Trenthorst F/ 8		8.3	
Trenthorst F/11		26.3	27.85
Trenthorst F/11		22.4	
Trenthorst F/11		31.1	
Trenthorst F/11		31.5	
Trenthorst F/ 29		22.3	17.78
Trenthorst F/ 29		25.3	
Trenthorst F/ 29		11.9	
Trenthorst F/ 29		11.5	

Tab. A.4 continued

Field	$\mu gTPFg^{-1}.d^{-1}$	Mean
Trenthorst F/ 51	11.4	10.14
Trenthorst F/ 51	9.5	
Trenthorst F/ 51	9.1	
Trenthorst F/ 51	10.6	
Mariensee- schlag1 /shallow	28.6	29.29
Mariensee- schlag1 /shallow	26.7	
Mariensee- schlag1 /shallow	38.7	
Mariensee- schlag1 /shallow	23.1	
Mariensee- schlag1 /deep	16.2	18.49
Mariensee- schlag1 /deep	20.1	
Mariensee- schlag1 /deep	20.3	
Mariensee- schlag1 /deep	17.3	
Mariensee- F/ kuhweide grass	53.8	29.90
Mariensee- F/ kuhweide grass	28.0	
Mariensee- F/ kuhweide grass	17.9	
Mariensee- F/ kuhweide grass	19.9	
Mariensee- F/ Vietingskamp succession	27.1	24.89
Mariensee- F/ Vietingskamp succession	27.2	
Mariensee- F/ Vietingskamp succession	24.4	
Mariensee- F/ Vietingskamp succession	20.7	
Mariensee- F/moorkamp	14.5	15.49
Mariensee- F/moorkamp	15.1	
Mariensee- F/moorkamp	22.4	
Mariensee- F/moorkamp	10.0	
Mariensee-F/ fuchsberg	12.1	16.14
Mariensee-F/ fuchsberg	18.6	
Mariensee-F/ fuchsberg	17.7	

Tab.A.5: Soil infiltration rate for the studied fields

Field	Plot	Season	Infiltration rate (mm h^{-1})	Mean
Braunschweig				
F/ 36-BS	4	Fall	280.8	301.86
F/ 36-BS	4	Fall	308.88	
F/ 36-BS	4	Fall	327.6	
F/ 36-BS	4	Fall	290.16	
F/ 36-BS	10	Fall	421.2	411.84
F/ 36-BS	10	Fall	374.4	
F/ 36-BS	10	Fall	439.92	
F/ 36-BS	10	Fall	411.84	
F/ 36-BS	12	Fall	383.76	376.74
F/ 36-BS	12	Fall	374.4	
F/ 36-BS	12	Fall	346.32	
F/ 36-BS	12	Fall	402.48	
F/ 4-BS	1.3.2	Fall	748.8	413.4
F/ 4-BS	1.3.2	Fall	655.2	
F/ 4-BS	1.3.2	Fall	468	
F/4-BS	1.3.2	Fall	149.76	
F/4-BS	1.3.2	Fall	159.12	
F/4-BS	1.3.2	Fall	299.52	
F/ 4-BS	2.3.2	Fall	168.48	152.88
F/ 4-BS	2.3.2	Fall	187.2	
F/ 4-BS	2.3.2	Fall	168.48	
F/4-BS	2.3.2	Fall	112.32	
F/4-BS	2.3.2	Fall	93.6	
F/4-BS	2.3.2	Fall	187.2	
F/ 4-BS	Succession	Spring	243.36	264.42
F/ 4-BS	Succession	Spring	280.8	
F/ 4-BS	Succession	Spring	234	
F/ 4-BS	Succession	Spring	299.52	
F/ 36-BS	4	Spring	215.28	107.64
F/ 36-BS	4	Spring	46.8	
F/ 36-BS	4	Spring	56.16	
F/ 36-BS	4	Spring	112.32	
F/10-BS	A	Spring	37.44	21.84
F/10-BS	A	Spring	9.36	
F/10-BS	A	Spring	18.72	
F/10-BS	B	Spring	28.08	43.68
F/10-BS	B	Spring	65.52	
F/10-BS	B	Spring	37.44	

Tab. A.5 continued

Field	Plot	Season	Infiltration rate (mm h^{-1})	Mean
F/7-BS	1	Spring	18.72	23.4
F/7-BS	1	Spring	28.08	
F/7-BS	23	Spring	18.72	32.76
F/7-BS	23	Spring	46.8	
F/7-BS	30	Spring	28.08	28.08
F/7-BS	30	Spring	28.08	
F/7-BS	32	Spring	37.44	56.16
F/7-BS	32	Spring	74.88	
Forest-BS	F	Spring	533.52	404.82
Forest-BS	F	Spring	318.24	
Forest-BS	F	Spring	393.12	
Forest-BS	F	Spring	374.4	
Trenthorst				
F/8 TREN	8	Spring	1404	1528.8
F/8 TREN	8	Spring	1684.8	
F/8 TREN	8	Spring	1497.6	
F/11 TREN	11	Spring	655.2	586.56
F/11 TREN	11	Spring	580.32	
F/11 TREN	11	Spring	524.16	
F/29 TREN	29	Spring	486.72	486.72
F/29 TREN	29	Spring	430.56	
F/29 TREN	29	Spring	542.88	
F/51 TREN	51	Spring	823.68	873.6
F/51 TREN	51	Spring	954.72	
F/51 TREN	51	Spring	842.4	
Mariensee				
F/schlag1-MAR	Shallow till	Fall	936	892.32
F/schlag1-MAR	Shallow till	Fall	992.16	
F/schlag1-MAR	Shallow till	Fall	748.8	
F/schlag1-MAR	Shallow till	Fall	767.52	
F/schlag1-MAR	Deep till	Fall	486.72	566.28
F/schlag1-MAR	Deep till	Fall	842.4	
F/schlag1-MAR	Deep till	Fall	374.4	
F/schlag1-MAR	Deep till	Fall	561.6	
F/ Grass-MAR	G	Fall	374.4	393.12
F/ Grass-MAR	G	Fall	393.12	
F/ Grass-MAR	G	Fall	374.4	
F/ Grass-MAR	G	Fall	430.56	

Tab. A.5 continued

Field	Plot	Season	Infiltration rate (mm h^{-1})	Mean
F/ Succession- MAR	S	Fall	561.6	453.96
F/ Succession- MAR	S	Fall	468	
F/ Succession- MAR	S	Fall	280.8	
F/ Succession- MAR	S	Fall	505.44	
F/ Moorkamp-MAR	15	Fall	280.8	280.8
F/ Moorkamp-MAR	8	Fall	205.92	
F/ Moorkamp-MAR	10	Fall	262.08	
F/ Moorkamp-MAR	11	Fall	374.4	
F/ Fuchsberg-MAR	4	Fall	243.36	212.16
F/ Fuchsberg-MAR	11	Fall	205.92	
F/ Fuchsberg-MAR	16	Fall	187.2	

Tab.A.6: Aggregate stability for the studied fields

Field	Depth (cm)	Aggregate stability	Mean
Braunschweig			
FV/10 - A BS	0-25	0.68	0.67
FV/10 - A BS	0-25	0.67	
FV/10 - A BS	0-25	0.67	
FV/10 - A BS	25-50	0.65	0.64
FV/10 - A BS	25-50	0.62	
FV/10 - A BS	25-50	0.64	
FV/10 - B BS	0-25	0.87	0.88
FV/10 - B BS	0-25	0.90	
FV/10 - B BS	0-25	0.86	
FV/10 - B BS	25-50	0.85	0.84
FV/10 - B BS	25-50	0.86	
FV/10 - B BS	25-50	0.82	
FV/7 - 1 BS	0-25	0.75	0.76
FV/7 - 1 BS	0-25	0.76	
FV/7 - 1 BS	0-25	0.77	
FV/7 - 1 BS	25-50	0.74	0.74
FV/7 - 1 BS	25-50	0.74	
FV/7 - 1 BS	25-50	0.74	
FV/7 - 23 BS	0-25	0.93	0.93
FV/7 - 23 BS	0-25	0.94	
FV/7 - 23 BS	0-25	0.92	
FV/7 - 23 BS	25-50	0.88	0.89
FV/7 - 23 BS	25-50	0.90	
FV/7 - 23 BS	25-50	0.90	
FV/7 - 30 BS	0-25	0.69	0.69
FV/7 - 30 BS	0-25	0.69	
FV/7 - 30 BS	0-25	0.68	
FV/7 - 30 BS	25-50	0.62	0.64
FV/7 - 30 BS	25-50	0.65	
FV/7 - 30 BS	25-50	0.65	
FV/7 - 32 BS	0-25	0.88	0.88
FV/7 - 32 BS	0-25	0.89	
FV/7 - 32 BS	0-25	0.87	
FV/7 - 32 BS	25-50	0.85	0.84
FV/7 - 32 BS	25-50	0.84	
FV/7 - 32 BS	25-50	0.83	
FV/4 1.3 BS	0-25	0.76	0.76
FV/4 1.3 BS	0-25	0.76	
FV/4 1.3 BS	0-25	0.76	
FV/4 1.3 BS	25-50	0.49	0.51
FV/4 1.3 BS	25-50	0.52	
FV/4 1.3 BS	25-50	0.52	

Tab. A.6 continued

Field	Depth (cm)	Aggregate stability	Mean
FV/4 2.3 BS	0-25	0.70	0.72
FV/4 2.3 BS	0-25	0.73	
FV/4 2.3 BS	0-25	0.73	
FV/4 2.3 BS	25-50	0.49	0.47
FV/4 2.3 BS	25-50	0.46	
FV/4 2.3 BS	25-50	0.46	
FV/4 Succession BS	0-25	0.84	0.85
FV/4 Succession BS	0-25	0.87	
FV/4 Succession BS	0-25	0.83	
FV/4 Succession BS	25-50	0.73	0.74
FV/4 Succession BS	25-50	0.73	
FV/4 Succession BS	25-50	0.77	
FOREST -BS	0-25	0.79	0.80
FOREST -BS	0-25	0.81	
FOREST -BS	0-25	0.79	
FOREST -BS	25-50	0.91	0.82
FOREST -BS	25-50	0.72	
FOREST -BS	25-50	0.84	
FV/36-4/ 1 BS	0-25	0.78	0.78
FV/36-4/ 1 BS	0-25	0.78	
FV/36-4/ 1 BS	0-25	0.78	
FV/36-4/ 1 BS	25-50	0.71	0.70
FV/36-4/ 1 BS	25-50	0.69	
FV/36-4/ 1 BS	25-50	0.70	
FV/36-4/ 2 BS	0-25	0.79	0.79
FV/36-4/ 2 BS	0-25	0.80	
FV/36-4/ 2 BS	0-25	0.79	
FV/36-4/ 2 BS	25-50	0.73	0.75
FV/36-4/ 2 BS	25-50	0.76	
FV/36-4/ 2 BS	25-50	0.75	
FV/36-4/ 3 BS	0-25	0.76	0.75
FV/36-4/ 3 BS	0-25	0.74	
FV/36-4/ 3 BS	0-25	0.76	
FV/36-4/ 3 BS	25-50	0.73	0.70
FV/36-4/ 3 BS	25-50	0.69	
FV/36-4/ 3 BS	25-50	0.67	
FV/36-4/ 4 BS	0-25	0.76	0.77
FV/36-4/ 4 BS	0-25	0.78	
FV/36-4/ 4 BS	0-25	0.77	
FV/36-4/ 4 BS	25-50	0.72	0.71
FV/36-4/ 4 BS	25-50	0.71	
FV/36-4/ 4 BS	25-50	0.71	

Tab. A.6 continued

Field	Depth (cm)	Aggregate stability	Mean
FV/36-10/ 1 BS	0-25	0.89	0.90
FV/36-10/ 1 BS	0-25	0.89	
FV/36-10/ 1 BS	0-25	0.91	
FV/36-10/ 1 BS	25-50	0.78	0.77
FV/36-10/ 1 BS	25-50	0.77	
FV/36-10/ 1 BS	25-50	0.76	
FV/36-10/ 2 BS	0-25	0.93	0.93
FV/36-10/ 2 BS	0-25	0.94	
FV/36-10/ 2 BS	0-25	0.93	
FV/36-10/ 2 BS	25-50	0.89	0.89
FV/36-10/ 2 BS	25-50	0.90	
FV/36-10/ 2 BS	25-50	0.89	
FV/36-10/ 3 BS	0-25	0.92	0.90
FV/36-10/ 3 BS	0-25	0.90	
FV/36-10/ 3 BS	0-25	0.90	
FV/36-10/ 3 BS	25-50	0.90	0.90
FV/36-10/ 3 BS	25-50	0.90	
FV/36-10/ 3 BS	25-50	0.89	
FV/36-10/ 4 BS	0-25	0.95	0.94
FV/36-10/ 4 BS	0-25	0.93	
FV/36-10/ 4 BS	0-25	0.93	
FV/36-10/ 4 BS	25-50	0.84	0.85
FV/36-10/ 4 BS	25-50	0.88	
FV/36-10/ 4 BS	25-50	0.84	
FV/36-12/ 1 BS	0-25	0.89	0.89
FV/36-12/ 1 BS	0-25	0.89	
FV/36-12/ 1 BS	0-25	0.91	
FV/36-12/ 1 BS	25-50	0.86	0.88
FV/36-12/ 1 BS	25-50	0.88	
FV/36-12/ 1 BS	25-50	0.89	
FV/36-12/ 2 BS	0-25	0.89	0.89
FV/36-12/ 2 BS	0-25	0.88	
FV/36-12/ 2 BS	0-25	0.90	
FV/36-12/ 2 BS	25-50	0.87	0.87
FV/36-12/ 2 BS	25-50	0.88	
FV/36-12/ 2 BS	25-50	0.87	
FV/36-12/ 3 BS	0-25	0.92	0.91
FV/36-12/ 3 BS	0-25	0.90	
FV/36-12/ 3 BS	0-25	0.91	
FV/36-12/ 3 BS	25-50	0.88	0.88
FV/36-12/ 3 BS	25-50	0.89	
FV/36-12/ 3 BS	25-50	0.89	

Tab. A.6 continued

Field	Depth (cm)	Aggregate stability	Mean
FV/36-12/ 4 BS	0-25	0.88	0.87
FV/36-12/ 4 BS	0-25	0.87	
FV/36-12/ 4 BS	0-25	0.87	
FV/36-12/ 4 BS	25-50	0.83	0.83
FV/36-12/ 4 BS	25-50	0.84	
FV/36-12/ 4 BS	25-50	0.81	
Mariensee			
Mariensee-Schlag1/deep	0-25	0.58	0.53
Mariensee-Schlag1/deep	0-25	0.48	
Mariensee-Schlag1/deep	0-25	0.52	
Mariensee-Schlag1/deep	25-50	0.67	0.57
Mariensee-Schlag1/deep	25-50	0.53	
Mariensee-Schlag1/deep	25-50	0.49	
Mariensee-Schlag1/shallow	0-25	0.65	0.71
Mariensee-Schlag1/shallow	0-25	0.75	
Mariensee-Schlag1/shallow	0-25	0.74	
Mariensee-Schlag1/shallow	25-50	0.73	0.80
Mariensee-Schlag1/shallow	25-50	0.73	
Mariensee-Schlag1/shallow	25-50	0.93	
Mariensee FV- Grass	0-25	0.94	0.94
Mariensee FV- Grass	0-25	0.94	
Mariensee FV- Grass	0-25	0.94	
Mariensee FV- Grass	25-50	0.93	0.91
Mariensee FV- Grass	25-50	0.90	
Mariensee FV- Grass	25-50	0.89	
Mariensee FV- Succession	0-25	0.97	0.97
Mariensee FV- Succession	0-25	0.96	
Mariensee FV- Succession	0-25	0.96	
Mariensee FV- Succession	25-50	0.79	0.83
Mariensee FV- Succession	25-50	0.88	
Mariensee FV- Succession	25-50	0.82	
Mariensee FV- Fuchsberg	0-25	0.86	0.87
Mariensee FV- Fuchsberg	0-25	0.89	
Mariensee FV- Fuchsberg	0-25	0.87	
Mariensee FV- Fuchsberg	25-50	0.55	0.48
Mariensee FV- Fuchsberg	25-50	0.44	
Mariensee FV- Fuchsberg	25-50	0.44	
Mariensee FV- Moorkamp	0-25	0.90	0.89
Mariensee FV- Moorkamp	0-25	0.86	
Mariensee FV- Moorkamp	0-25	0.91	
Mariensee FV- Moorkamp	25-50	0.57	0.62
Mariensee FV- Moorkamp	25-50	0.65	
Mariensee FV- Moorkamp	25-50	0.65	

Tab. A.6 continued

Field	Depth (cm)	Aggregate stability	Mean
Trenthorst			
FV/11 TRE	0-25	0.87	0.88
FV/11 TRE	0-25	0.89	
FV/11 TRE	0-25	0.88	
FV/11 TRE	25-50	0.81	0.81
FV/11 TRE	25-50	0.81	
FV/11 TRE	25-50	0.80	
FV/8 TRE	0-25	0.92	0.91
FV/8 TRE	0-25	0.91	
FV/8 TRE	0-25	0.91	
FV/8 TRE	25-50	0.86	0.87
FV/8 TRE	25-50	0.87	
FV/8 TRE	25-50	0.87	
FV/29 TRE	0-25	0.87	0.87
FV/29 TRE	0-25	0.88	
FV/29 TRE	0-25	0.87	
FV/29 TRE	25-50	0.76	0.76
FV/29 TRE	25-50	0.78	
FV/29 TRE	25-50	0.75	
FV/51 TRE	0-25	0.80	0.81
FV/51 TRE	0-25	0.81	
FV/51 TRE	0-25	0.82	
FV/51 TRE	25-50	0.79	0.78
FV/51 TRE	25-50	0.79	
FV/51 TRE	25-50	0.76	

Tab. A.7: Soil water retention for the studied fields in Trenthorst

Trenthorst	Depth	Fresh soil	pF 1,8	pF 2	pF 2,5	pF 4,2
Field	cm	Water	Water	Water	Water	Water
		%	%	%	%	%
FV/51 TREN	2-8	15.05	21.74	21.16	11.05	8.73
FV/51 TREN	2-8	14.97	20.14	18.94	9.49	8.89
FV/51 TREN	2-8	14.11	20.79	19.64	10.00	9.31
FV/51 TREN	2-8	14.34	20.66	19.62	10.05	8.31
FV/51 TREN	10 - 16	15.08	21.63	20.72	10.70	9.72
FV/51 TREN	10 - 16	14.27	20.03	19.72	10.10	9.18
FV/51 TREN	10 - 16	14.95	21.63	20.87	11.23	7.91
FV/51 TREN	10 - 16	15.41	22.09	21.28	11.09	9.68
FV/51 TREN	18 - 24	17.28	24.03	23.39	12.40	9.70
FV/51 TREN	18 - 24	17.07	23.59	23.31	12.64	9.80
FV/51 TREN	18 - 24	17.02	24.62	24.15	13.11	9.11
FV/51 TREN	18 - 24	16.83	24.03	23.21	12.12	5.99
FV/51 TREN	26 - 32	17.80	24.11	23.34	12.38	9.52
FV/51 TREN	26 - 32	18.48	25.77	24.73	13.85	9.21
FV/51 TREN	26 - 32	18.01	25.24	24.72	13.39	9.92
FV/51 TREN	26 - 32	17.10	25.50	25.09	13.59	9.36
FV/11 TREN	2-8	11.56	15.99	14.83	7.24	9.72
FV/11 TREN	2-8	10.83	16.25	15.39	7.56	6.14
FV/11 TREN	2-8	10.79	16.64	14.95	7.34	6.03
FV/11 TREN	2-8	11.55	17.68	16.44	8.13	5.75
FV/11 TREN	10 - 16	11.98	17.80	16.97	8.21	5.51
FV/11 TREN	10 - 16	11.58	17.23	16.14	8.09	5.96
FV/11 TREN	10 - 16	11.48	18.41	17.52	9.06	6.26
FV/11 TREN	10 - 16	11.29	17.91	16.91	8.41	6.00
FV/11 TREN	18 - 24	13.83	19.53	18.13	9.24	5.80
FV/11 TREN	18 - 24	13.87	19.15	17.63	9.04	6.25
FV/11 TREN	18 - 24	14.30	20.99	19.43	9.62	5.88
FV/11 TREN	18 - 24	13.59	19.34	18.06	9.19	6.09
FV/11 TREN	26 - 32	14.41	21.59	20.59	11.04	6.02
FV/11 TREN	26 - 32	14.83	22.62	21.15	10.42	6.05
FV/11 TREN	26 - 32	13.45	21.15	20.44	10.25	6.40
FV/11 TREN	26 - 32	13.79	21.80	20.97	11.09	5.79
FV/29 TREN	2-8	22.14	27.70	25.66	10.46	14.22
FV/29 TREN	2-8	22.45	27.01	25.26	10.94	14.38
FV/29 TREN	2-8	21.64	26.63	24.88	10.73	15.95
FV/29 TREN	2-8	22.58	26.17	24.31	10.83	14.87
FV/29 TREN	10 - 16	22.92	26.02	24.34	12.21	15.04
FV/29 TREN	10 - 16	21.05	26.69	25.19	12.11	11.76
FV/29 TREN	10 - 16	20.14	25.32	24.03	11.62	10.87
FV/29 TREN	10 - 16	20.50	25.30	23.82	11.22	10.83

Tab. A.7 continued

Trenthorst	Depth	Fresh soil	pF 1,8	pF 2	pF 2,5	pF 4,2
Field	cm	Water	Water	Water	Water	Water
		%	%	%	%	%
FV/29 TREN	18 - 24	17.20	21.74	20.31	10.17	6.81
FV/29 TREN	18 - 24	17.74	21.48	20.01	10.29	6.40
FV/29 TREN	18 - 24	17.72	20.78	19.00	9.49	7.33
FV/29 TREN	18 - 24	15.22	19.48	18.13	9.19	7.56
FV/29 TREN	26 - 32	15.54	21.48	20.16	10.89	6.31
FV/29 TREN	26 - 32	15.71	21.97	20.69	10.84	6.97
FV/29 TREN	26 - 32	15.20	20.22	18.85	9.94	6.75
FV/29 TREN	26 - 32	14.14	20.66	19.31	9.87	6.94
FV/8 TREN	2-8	14.61	18.09	17.44	8.66	8.23
FV/8 TREN	2-8	14.28	18.31	17.49	9.54	7.87
FV/8 TREN	2-8	13.94	16.94	16.41	8.09	8.29
FV/8 TREN	2-8	14.45	18.46	17.24	8.21	8.01
FV/8 TREN	10 - 16	15.06	18.33	17.49	8.73	8.39
FV/8 TREN	10 - 16	14.51	17.63	17.10	8.58	8.13
FV/8 TREN	10 - 16	14.27	17.61	16.37	8.02	8.89
FV/8 TREN	10 - 16	14.19	16.00	15.34	7.39	8.09
FV/8 TREN	18 - 24	15.51	18.47	17.87	9.42	8.73
FV/8 TREN	18 - 24	15.99	18.75	17.35	8.67	8.51
FV/8 TREN	18 - 24	15.53	18.27	17.41	9.16	8.97
FV/8 TREN	18 - 24	15.60	18.37	17.72	8.94	7.40
FV/8 TREN	26 - 32	15.05	20.92	20.48	11.04	8.91
FV/8 TREN	26 - 32	16.59	20.44	19.96	10.77	9.00
FV/8 TREN	26 - 32	15.39	20.55	19.53	10.31	8.95
FV/8 TREN	26 - 32	14.90	18.86	17.99	9.34	8.33

Tab. A. 8: Soil dry bulk density for the studied fields in Braunschweig

Site	Field	Depth (cm)	Dry bulk density (gcm-3)	Mean
Braunschweig	**FV/10**			
Braunschweig	**FV/10-A**	2-8	1.58	1.55
Braunschweig	**FV/10-A**	2-8	1.55	
Braunschweig	**FV/10-A**	2-8	1.55	
Braunschweig	**FV/10-A**	2-8	1.56	
Braunschweig	**FV/10-A**	2-8	1.49	
Braunschweig	**FV/10-A**	2-8	1.57	
Braunschweig	**FV/10-A**	10-16	1.57	1.56
Braunschweig	**FV/10-A**	10-16	1.61	
Braunschweig	**FV/10-A**	10-16	1.59	
Braunschweig	**FV/10-A**	10-16	1.53	
Braunschweig	**FV/10-A**	10-16	1.52	
Braunschweig	**FV/10-A**	10-16	1.52	
Braunschweig	**FV/10-A**	18-24	1.63	1.53
Braunschweig	**FV/10-A**	18-24	1.61	
Braunschweig	**FV/10-A**	18-24	1.47	
Braunschweig	**FV/10-A**	18-24	1.52	
Braunschweig	**FV/10-A**	18-24	1.51	
Braunschweig	**FV/10-A**	18-24	1.44	
Braunschweig	**FV/10-A**	26 -32	1.44	1.43
Braunschweig	**FV/10-A**	26 -32	1.34	
Braunschweig	**FV/10-A**	26 -32	1.40	
Braunschweig	**FV/10-A**	26 -32	1.44	
Braunschweig	**FV/10-A**	26 -32	1.49	
Braunschweig	**FV/10-A**	26 -32	1.47	
Braunschweig	**FV/10-A**	34 - 40	1.68	1.60
Braunschweig	**FV/10-A**	34 - 40	1.57	
Braunschweig	**FV/10-A**	34 - 40	1.59	
Braunschweig	**FV/10-A**	34 - 40	1.61	
Braunschweig	**FV/10-A**	34 - 40	1.54	
Braunschweig	**FV/10-A**	34 - 40	1.61	
Braunschweig	**FV/10-B**	2-8	1.55	1.57
Braunschweig	**FV/10-B**	2-8	1.61	
Braunschweig	**FV/10-B**	2-8	1.57	
Braunschweig	**FV/10-B**	2-8	1.57	
Braunschweig	**FV/10-B**	2-8	1.54	
Braunschweig	**FV/10-B**	2-8	1.56	
Braunschweig	**FV/10-B**	10-16	1.58	1.54
Braunschweig	**FV/10-B**	10-16	1.52	
Braunschweig	**FV/10-B**	10-16	1.54	
Braunschweig	**FV/10-B**	10-16	1.57	
Braunschweig	**FV/10-B**	10-16	1.49	
Braunschweig	**FV/10-B**	10-16	1.54	
Braunschweig	**FV/10-B**	18-24	1.48	1.47
Braunschweig	**FV/10-B**	18-24	1.45	
Braunschweig	**FV/10-B**	18-24	1.53	
Braunschweig	**FV/10-B**	18-24	1.47	
Braunschweig	**FV/10-B**	18-24	1.44	
Braunschweig	**FV/10-B**	18-24	1.45	

Tab. A.8 continued

Site	Field	Depth (cm)	Dry bulk density (gcm-3)	Mean
Braunschweig	**FV/10-B**	26 -32	1.56	1.56
Braunschweig	**FV/10-B**	26 -32	1.51	
Braunschweig	**FV/10-B**	26 -32	1.61	
Braunschweig	**FV/10-B**	26 -32	1.59	
Braunschweig	**FV/10-B**	26 -32	1.55	
Braunschweig	**FV/10-B**	26 -32	1.53	
Braunschweig	**FV/10-B**	34 - 40	1.67	1.62
Braunschweig	**FV/10-B**	34 - 40	1.66	
Braunschweig	**FV/10-B**	34 - 40	1.60	
Braunschweig	**FV/10-B**	34 - 40	1.66	
Braunschweig	**FV/10-B**	34 - 40	1.64	
Braunschweig	**FV/10-B**	34 - 40	1.51	
Braunschweig	**FV/7**			
Braunschweig	**FV7/1**	2-8	1.48	1.53
Braunschweig	**FV7/1**	2-8	1.49	
Braunschweig	**FV7/1**	2-8	1.58	
Braunschweig	**FV7/1**	2-8	1.56	
Braunschweig	**FV7/1**	2-8	1.52	
Braunschweig	**FV7/1**	2-8	1.54	
Braunschweig	**FV7/1**	10-16	1.51	1.53
Braunschweig	**FV7/1**	10-16	1.53	
Braunschweig	**FV7/1**	10-16	1.54	
Braunschweig	**FV7/1**	10-16	1.52	
Braunschweig	**FV7/1**	10-16	1.56	
Braunschweig	**FV7/1**	10-16	1.53	
Braunschweig	**FV7/1**	18-24	1.66	1.70
Braunschweig	**FV7/1**	18-24	1.68	
Braunschweig	**FV7/1**	18-24	1.75	
Braunschweig	**FV7/1**	18-24	1.69	
Braunschweig	**FV7/1**	18-24	1.74	
Braunschweig	**FV7/1**	18-24	1.66	
Braunschweig	**FV7/1**	26-32	1.61	1.63
Braunschweig	**FV7/1**	26-32	1.62	
Braunschweig	**FV7/1**	26-32	1.69	
Braunschweig	**FV7/1**	26-32	1.54	
Braunschweig	**FV7/1**	26-32	1.66	
Braunschweig	**FV7/1**	26-32	1.64	
Braunschweig	**FV7/23**	2-8	1.42	1.39
Braunschweig	**FV7/23**	2-8	1.39	
Braunschweig	**FV7/23**	2-8	1.35	
Braunschweig	**FV7/23**	2-8	1.38	
Braunschweig	**FV7/23**	2-8	1.42	
Braunschweig	**FV7/23**	2-8	1.41	
Braunschweig	**FV7/23**	10-16	1.45	1.45
Braunschweig	**FV7/23**	10-16	1.50	
Braunschweig	**FV7/23**	10-16	1.39	
Braunschweig	**FV7/23**	10-16	1.42	
Braunschweig	**FV7/23**	10-16	1.46	
Braunschweig	**FV7/23**	10-16	1.48	

Tab. A.8 continued

Site	Field	Depth (cm)	Dry bulk density (gcm-3)	Mean
Braunschweig	**FV7/23**	18-24	1.51	1.58
Braunschweig	**FV7/23**	18-24	1.59	
Braunschweig	**FV7/23**	18-24	1.60	
Braunschweig	**FV7/23**	18-24	1.59	
Braunschweig	**FV7/23**	18-24	1.59	
Braunschweig	**FV7/23**	18-24	1.58	
Braunschweig	**FV7/23**	26-32	1.52	1.58
Braunschweig	**FV7/23**	26-32	1.55	
Braunschweig	**FV7/23**	26-32	1.60	
Braunschweig	**FV7/23**	26-32	1.69	
Braunschweig	**FV7/23**	26-32	1.57	
Braunschweig	**FV7/23**	26-32	1.54	
Braunschweig	**FV7/30**	2-8	1.50	1.54
Braunschweig	**FV7/30**	2-8	1.52	
Braunschweig	**FV7/30**	2-8	1.54	
Braunschweig	**FV7/30**	2-8	1.59	
Braunschweig	**FV7/30**	2-8	1.53	
Braunschweig	**FV7/30**	2-8	1.58	
Braunschweig	**FV7/30**	10-16	1.48	1.47
Braunschweig	**FV7/30**	10-16	1.42	
Braunschweig	**FV7/30**	10-16	1.52	
Braunschweig	**FV7/30**	10-16	1.46	
Braunschweig	**FV7/30**	10-16	1.38	
Braunschweig	**FV7/30**	10-16	1.56	
Braunschweig	**FV7/30**	18-24	1.62	1.54
Braunschweig	**FV7/30**	18-24	1.43	
Braunschweig	**FV7/30**	18-24	1.56	
Braunschweig	**FV7/30**	18-24	1.55	
Braunschweig	**FV7/30**	18-24	1.55	
Braunschweig	**FV7/30**	18-24	1.52	
Braunschweig	**FV7/30**	26-32	1.53	1.63
Braunschweig	**FV7/30**	26-32	1.71	
Braunschweig	**FV7/30**	26-32	1.75	
Braunschweig	**FV7/30**	26-32	1.52	
Braunschweig	**FV7/30**	26-32	1.60	
Braunschweig	**FV7/30**	26-32	1.65	
Braunschweig	**FV7/32**	2-8	1.60	1.59
Braunschweig	**FV7/32**	2-8	1.56	
Braunschweig	**FV7/32**	2-8	1.59	
Braunschweig	**FV7/32**	2-8	1.56	
Braunschweig	**FV7/32**	2-8	1.63	
Braunschweig	**FV7/32**	2-8	1.60	
Braunschweig	**FV7/32**	10-16	1.60	1.56
Braunschweig	**FV7/32**	10-16	1.61	
Braunschweig	**FV7/32**	10-16	1.54	
Braunschweig	**FV7/32**	10-16	1.52	
Braunschweig	**FV7/32**	10-16	1.53	
Braunschweig	**FV7/32**	10-16	1.58	

Tab. A.8 continued

Site	Field	Depth (cm)	Dry bulk density (gcm-3)	Mean
Braunschweig	**FV7/32**	18-24	1.45	1.47
Braunschweig	**FV7/32**	18-24	1.48	
Braunschweig	**FV7/32**	18-24	1.47	
Braunschweig	**FV7/32**	18-24	1.41	
Braunschweig	**FV7/32**	18-24	1.50	
Braunschweig	**FV7/32**	18-24	1.50	
Braunschweig	**FV7/32**	26-32	1.54	1.56
Braunschweig	**FV7/32**	26-32	1.46	
Braunschweig	**FV7/32**	26-32	1.44	
Braunschweig	**FV7/32**	26-32	1.60	
Braunschweig	**FV7/32**	26-32	1.63	
Braunschweig	**FV7/32**	26-32	1.67	
Braunschweig	**Forest**	2-8	0.87	0.92
Braunschweig	**Forest**	2-8	0.94	
Braunschweig	**Forest**	2-8	0.89	
Braunschweig	**Forest**	2-8	0.84	
Braunschweig	**Forest**	2-8	1.01	
Braunschweig	**Forest**	2-8	0.95	
Braunschweig	**Forest**	10-16	1.40	1.56
Braunschweig	**Forest**	10-16	1.67	
Braunschweig	**Forest**	10-16	1.59	
Braunschweig	**Forest**	10-16	1.46	
Braunschweig	**Forest**	10-16	1.62	
Braunschweig	**Forest**	10-16	1.64	
Braunschweig	**Forest**	18-24	1.35	1.56
Braunschweig	**Forest**	18-24	1.59	
Braunschweig	**Forest**	18-24	1.70	
Braunschweig	**Forest**	18-24	1.58	
Braunschweig	**Forest**	18-24	1.56	
Braunschweig	**Forest**	18-24	1.57	
Braunschweig	**Forest**	26-32	1.48	1.55
Braunschweig	**Forest**	26-32	1.57	
Braunschweig	**Forest**	26-32	1.59	
Braunschweig	**Forest**	26-32	1.60	
Braunschweig	**Forest**	26-32	1.35	
Braunschweig	**Forest**	26-32	1.72	
Braunschweig	**Forest**	34-40	1.54	1.65
Braunschweig	**Forest**	34-40	1.78	
Braunschweig	**Forest**	34-40	1.62	
Braunschweig	**Forest**	34-40	1.59	
Braunschweig	**Forest**	34-40	1.68	
Braunschweig	**Forest**	34-40	1.70	
Braunschweig	**Succession**	2-8	1.37	1.44
Braunschweig	**Succession**	2-8	1.48	
Braunschweig	**Succession**	2-8	1.43	
Braunschweig	**Succession**	2-8	1.47	
Braunschweig	**Succession**	2-8	1.47	
Braunschweig	**Succession**	2-8	1.42	

Tab. A.8 continued

Site	Field	Depth (cm)	Dry bulk density (gcm-3)	Mean
Braunschweig	**Succession**	10-16	1.46	1.53
Braunschweig	**Succession**	10-16	1.69	
Braunschweig	**Succession**	10-16	1.45	
Braunschweig	**Succession**	10-16	1.59	
Braunschweig	**Succession**	10-16	1.52	
Braunschweig	**Succession**	10-16	1.44	
Braunschweig	**Succession**	18-24	1.48	1.47
Braunschweig	**Succession**	18-24	1.54	
Braunschweig	**Succession**	18-24	1.51	
Braunschweig	**Succession**	18-24	1.44	
Braunschweig	**Succession**	18-24	1.46	
Braunschweig	**Succession**	18-24	1.39	
Braunschweig	**Succession**	26-32	1.27	1.45
Braunschweig	**Succession**	26-32	1.53	
Braunschweig	**Succession**	26-32	1.42	
Braunschweig	**Succession**	26-32	1.48	
Braunschweig	**Succession**	26-32	1.48	
Braunschweig	**Succession**	26-32	1.50	
Braunschweig	**Succession**	34-40	1.54	1.45
Braunschweig	**Succession**	34-40	1.43	
Braunschweig	**Succession**	34-40	1.45	
Braunschweig	**Succession**	34-40	1.43	
Braunschweig	**Succession**	34-40	1.44	
Braunschweig	**Succession**	34-40	1.42	
Braunschweig	**FV/36**			
Braunschweig	**FV10/1**	2-8	1.18	1.23
Braunschweig	**FV10/1**	2-8	1.28	
Braunschweig	**FV10/1**	2-8	1.29	
Braunschweig	**FV10/1**	2-8	1.31	
Braunschweig	**FV10/1**	2-8	1.08	
Braunschweig	**FV10/1**	2-8	1.25	
Braunschweig	**FV10/1**	10-16	1.37	1.29
Braunschweig	**FV10/1**	10-16	1.28	
Braunschweig	**FV10/1**	10-16	1.33	
Braunschweig	**FV10/1**	10-16	1.19	
Braunschweig	**FV10/1**	10-16	1.24	
Braunschweig	**FV10/1**	10-16	1.34	
Braunschweig	**FV10/1**	18-24	1.31	1.26
Braunschweig	**FV10/1**	18-24	1.14	
Braunschweig	**FV10/1**	18-24	1.31	
Braunschweig	**FV10/1**	18-24	1.29	
Braunschweig	**FV10/1**	18-24	1.30	
Braunschweig	**FV10/1**	18-24	1.22	
Braunschweig	**FV10/1**	26-32	1.32	1.34
Braunschweig	**FV10/1**	26-32	1.37	
Braunschweig	**FV10/1**	26-32	1.33	
Braunschweig	**FV10/1**	26-32	1.28	
Braunschweig	**FV10/1**	26-32	1.41	
Braunschweig	**FV10/1**	26-32	1.32	

Tab. A.8 continued

Site	Field	Depth (cm)	Dry bulk density (gcm-3)	Mean
Braunschweig	**FV10/1**	34-40	1.33	1.36
Braunschweig	**FV10/1**	34-40	1.47	
Braunschweig	**FV10/1**	34-40	1.35	
Braunschweig	**FV10/1**	34-40	1.43	
Braunschweig	**FV10/1**	34-40	1.24	
Braunschweig	**FV10/1**	34-40	1.37	
Braunschweig	**FV10/2**	2-8	1.36	1.33
Braunschweig	**FV10/2**	2-8	1.30	
Braunschweig	**FV10/2**	2-8	1.34	
Braunschweig	**FV10/2**	2-8	1.34	
Braunschweig	**FV10/2**	2-8	1.34	
Braunschweig	**FV10/2**	2-8	1.33	
Braunschweig	**FV10/2**	10-16	1.42	1.38
Braunschweig	**FV10/2**	10-16	1.36	
Braunschweig	**FV10/2**	10-16	1.33	
Braunschweig	**FV10/2**	10-16	1.32	
Braunschweig	**FV10/2**	10-16	1.45	
Braunschweig	**FV10/2**	10-16	1.40	
Braunschweig	**FV10/2**	18-24	1.32	1.28
Braunschweig	**FV10/2**	18-24	1.24	
Braunschweig	**FV10/2**	18-24	1.27	
Braunschweig	**FV10/2**	18-24	1.25	
Braunschweig	**FV10/2**	18-24	1.36	
Braunschweig	**FV10/2**	18-24	1.26	
Braunschweig	**FV10/2**	26-32	1.31	1.32
Braunschweig	**FV10/2**	26-32	1.26	
Braunschweig	**FV10/2**	26-32	1.35	
Braunschweig	**FV10/2**	26-32	1.33	
Braunschweig	**FV10/2**	26-32	1.40	
Braunschweig	**FV10/2**	26-32	1.28	
Braunschweig	**FV10/2**	34-40	1.34	1.35
Braunschweig	**FV10/2**	34-40	1.33	
Braunschweig	**FV10/2**	34-40	1.37	
Braunschweig	**FV10/2**	34-40	1.28	
Braunschweig	**FV10/2**	34-40	1.39	
Braunschweig	**FV10/2**	34-40	1.37	
Braunschweig	**FV10/3**	2-8	1.26	1.30
Braunschweig	**FV10/3**	2-8	1.39	
Braunschweig	**FV10/3**	2-8	1.31	
Braunschweig	**FV10/3**	2-8	1.28	
Braunschweig	**FV10/3**	2-8	1.28	
Braunschweig	**FV10/3**	2-8	1.29	
Braunschweig	**FV10/3**	10-16	1.33	1.28
Braunschweig	**FV10/3**	10-16	1.38	
Braunschweig	**FV10/3**	10-16	1.15	
Braunschweig	**FV10/3**	10-16	1.19	
Braunschweig	**FV10/3**	10-16	1.26	
Braunschweig	**FV10/3**	10-16	1.36	

Tab. A.8 continued

Site	Field	Depth (cm)	Dry bulk density (gcm-3)	Mean
Braunschweig	**FV10/3**	18-24	1.26	1.24
Braunschweig	**FV10/3**	18-24	1.26	
Braunschweig	**FV10/3**	18-24	1.19	
Braunschweig	**FV10/3**	18-24	1.17	
Braunschweig	**FV10/3**	18-24	1.33	
Braunschweig	**FV10/3**	18-24	1.21	
Braunschweig	**FV10/3**	26-32	1.39	1.34
Braunschweig	**FV10/3**	26-32	1.29	
Braunschweig	**FV10/3**	26-32	1.34	
Braunschweig	**FV10/3**	26-32	1.34	
Braunschweig	**FV10/3**	26-32	1.33	
Braunschweig	**FV10/3**	34-40	1.62	1.56
Braunschweig	**FV10/3**	34-40	1.58	
Braunschweig	**FV10/3**	34-40	1.60	
Braunschweig	**FV10/3**	34-40	1.56	
Braunschweig	**FV10/3**	34-40	1.50	
Braunschweig	**FV10/3**	34-40	1.51	
Braunschweig	**FV10/4**	2-8	1.27	1.32
Braunschweig	**FV10/4**	2-8	1.41	
Braunschweig	**FV10/4**	2-8	1.38	
Braunschweig	**FV10/4**	2-8	1.25	
Braunschweig	**FV10/4**	2-8	1.39	
Braunschweig	**FV10/4**	2-8	1.21	
Braunschweig	**FV10/4**	10-16	1.42	1.39
Braunschweig	**FV10/4**	10-16	1.34	
Braunschweig	**FV10/4**	10-16	1.39	
Braunschweig	**FV10/4**	10-16	1.42	
Braunschweig	**FV10/4**	10-16	1.43	
Braunschweig	**FV10/4**	10-16	1.36	
Braunschweig	**FV10/4**	18-24	1.40	1.34
Braunschweig	**FV10/4**	18-24	1.28	
Braunschweig	**FV10/4**	18-24	1.31	
Braunschweig	**FV10/4**	18-24	1.35	
Braunschweig	**FV10/4**	18-24	1.32	
Braunschweig	**FV10/4**	18-24	1.37	
Braunschweig	**FV10/4**	26-32	1.45	1.42
Braunschweig	**FV10/4**	26-32	1.42	
Braunschweig	**FV10/4**	26-32	1.38	
Braunschweig	**FV10/4**	26-32	1.47	
Braunschweig	**FV10/4**	26-32	1.42	
Braunschweig	**FV10/4**	26-32	1.36	
Braunschweig	**FV10/4**	34-40	1.51	1.52
Braunschweig	**FV10/4**	34-40	1.51	
Braunschweig	**FV10/4**	34-40	1.55	
Braunschweig	**FV10/4**	34-40	1.49	
Braunschweig	**FV10/4**	34-40	1.51	
Braunschweig	**FV10/4**	34-40	1.53	

Tab. A.8 continued

Site	Field	Depth (cm)	Dry bulk density (gcm-3)	Mean
Braunschweig	**FV 4/1**	2-8	1.36	1.42
Braunschweig	**FV 4/1**	2-8	1.48	
Braunschweig	**FV 4/1**	2-8	1.32	
Braunschweig	**FV 4/1**	2-8	1.40	
Braunschweig	**FV 4/1**	2-8	1.51	
Braunschweig	**FV 4/1**	2-8	1.48	
Braunschweig	**FV 4/1**	10-16	1.48	1.50
Braunschweig	**FV 4/1**	10-16	1.52	
Braunschweig	**FV 4/1**	10-16	1.48	
Braunschweig	**FV 4/1**	10-16	1.53	
Braunschweig	**FV 4/1**	10-16	1.51	
Braunschweig	**FV 4/1**	10-16	1.48	
Braunschweig	**FV 4/1**	18-24	1.49	1.46
Braunschweig	**FV 4/1**	18-24	1.36	
Braunschweig	**FV 4/1**	18-24	1.53	
Braunschweig	**FV 4/1**	18-24	1.45	
Braunschweig	**FV 4/1**	18-24	1.48	
Braunschweig	**FV 4/1**	18-24	1.47	
Braunschweig	**FV 4/1**	26-32	1.49	1.54
Braunschweig	**FV 4/1**	26-32	1.62	
Braunschweig	**FV 4/1**	26-32	1.53	
Braunschweig	**FV 4/1**	26-32	1.49	
Braunschweig	**FV 4/1**	26-32	1.55	
Braunschweig	**FV 4/1**	26-32	1.55	
Braunschweig	**FV 4/1**	34-40	1.58	1.57
Braunschweig	**FV 4/1**	34-40	1.64	
Braunschweig	**FV 4/1**	34-40	1.48	
Braunschweig	**FV 4/1**	34-40	1.59	
Braunschweig	**FV 4/1**	34-40	1.52	
Braunschweig	**FV 4/1**	34-40	1.59	
Braunschweig	**FV 4/2**	2-8	1.51	1.44
Braunschweig	**FV 4/2**	2-8	1.53	
Braunschweig	**FV 4/2**	2-8	1.41	
Braunschweig	**FV 4/2**	2-8	1.30	
Braunschweig	**FV 4/2**	2-8	1.58	
Braunschweig	**FV 4/2**	2-8	1.31	
Braunschweig	**FV 4/2**	10-16	1.37	1.40
Braunschweig	**FV 4/2**	10-16	1.42	
Braunschweig	**FV 4/2**	10-16	1.41	
Braunschweig	**FV 4/2**	10-16	1.48	
Braunschweig	**FV 4/2**	10-16	1.44	
Braunschweig	**FV 4/2**	10-16	1.31	
Braunschweig	**FV 4/2**	18-24	1.35	1.35
Braunschweig	**FV 4/2**	18-24	1.34	
Braunschweig	**FV 4/2**	18-24	1.33	
Braunschweig	**FV 4/2**	18-24	1.27	
Braunschweig	**FV 4/2**	18-24	1.46	
Braunschweig	**FV 4/2**	18-24	1.33	

Tab. A.8 continued

Site	Field	Depth (cm)	Dry bulk density (gcm-3)	Mean
Braunschweig	**FV 4/2**	26-32	1.38	1.43
Braunschweig	**FV 4/2**	26-32	1.36	
Braunschweig	**FV 4/2**	26-32	1.43	
Braunschweig	**FV 4/2**	26-32	1.52	
Braunschweig	**FV 4/2**	26-32	1.38	
Braunschweig	**FV 4/2**	26-32	1.52	
Braunschweig	**FV 4/2**	34-40	1.44	1.47
Braunschweig	**FV 4/2**	34-40	1.52	
Braunschweig	**FV 4/2**	34-40	1.53	
Braunschweig	**FV 4/2**	34-40	1.50	
Braunschweig	**FV 4/2**	34-40	1.37	
Braunschweig	**FV 4/2**	34-40	1.44	
Braunschweig	**FV 4/3**	2-8	1.55	1.51
Braunschweig	**FV 4/3**	2-8	1.49	
Braunschweig	**FV 4/3**	2-8	1.51	
Braunschweig	**FV 4/3**	2-8	1.40	
Braunschweig	**FV 4/3**	2-8	1.54	
Braunschweig	**FV 4/3**	2-8	1.57	
Braunschweig	**FV 4/3**	10-16	1.63	1.51
Braunschweig	**FV 4/3**	10-16	1.49	
Braunschweig	**FV 4/3**	10-16	1.46	
Braunschweig	**FV 4/3**	10-16	1.53	
Braunschweig	**FV 4/3**	10-16	1.55	
Braunschweig	**FV 4/3**	10-16	1.43	
Braunschweig	**FV 4/3**	18-24	1.49	1.50
Braunschweig	**FV 4/3**	18-24	1.48	
Braunschweig	**FV 4/3**	18-24	1.53	
Braunschweig	**FV 4/3**	18-24	1.45	
Braunschweig	**FV 4/3**	18-24	1.55	
Braunschweig	**FV 4/3**	18-24	1.49	
Braunschweig	**FV 4/3**	26-32	1.50	1.47
Braunschweig	**FV 4/3**	26-32	1.45	
Braunschweig	**FV 4/3**	26-32	1.42	
Braunschweig	**FV 4/3**	26-32	1.43	
Braunschweig	**FV 4/3**	26-32	1.50	
Braunschweig	**FV 4/3**	26-32	1.53	
Braunschweig	**FV 4/3**	34-40	1.56	1.60
Braunschweig	**FV 4/3**	34-40	1.52	
Braunschweig	**FV 4/3**	34-40	1.70	
Braunschweig	**FV 4/3**	34-40	1.63	
Braunschweig	**FV 4/3**	34-40	1.55	
Braunschweig	**FV 4/3**	34-40	1.62	
Braunschweig	**FV 4/4**	2-8	1.25	1.27
Braunschweig	**FV 4/4**	2-8	1.34	
Braunschweig	**FV 4/4**	2-8	1.19	
Braunschweig	**FV 4/4**	2-8	1.31	
Braunschweig	**FV 4/4**	2-8	1.40	
Braunschweig	**FV 4/4**	2-8	1.12	

Tab. A.8 continued

Site	Field	Depth (cm)	Dry bulk density (gcm-3)	Mean
Braunschweig	**FV 4/4**	10-16	1.43	1.44
Braunschweig	**FV 4/4**	10-16	1.40	
Braunschweig	**FV 4/4**	10-16	1.50	
Braunschweig	**FV 4/4**	10-16	1.66	
Braunschweig	**FV 4/4**	10-16	1.27	
Braunschweig	**FV 4/4**	10-16	1.38	
Braunschweig	**FV 4/4**	18-24	1.36	1.35
Braunschweig	**FV 4/4**	18-24	1.38	
Braunschweig	**FV 4/4**	18-24	1.35	
Braunschweig	**FV 4/4**	18-24	1.37	
Braunschweig	**FV 4/4**	18-24	1.28	
Braunschweig	**FV 4/4**	18-24	1.36	
Braunschweig	**FV 4/4**	26-32	1.48	1.43
Braunschweig	**FV 4/4**	26-32	1.40	
Braunschweig	**FV 4/4**	26-32	1.34	
Braunschweig	**FV 4/4**	26-32	1.47	
Braunschweig	**FV 4/4**	26-32	1.47	
Braunschweig	**FV 4/4**	26-32	1.41	
Braunschweig	**FV 4/4**	34-40	1.50	1.57
Braunschweig	**FV 4/4**	34-40	1.50	
Braunschweig	**FV 4/4**	34-40	1.52	
Braunschweig	**FV 4/4**	34-40	1.57	
Braunschweig	**FV 4/4**	34-40	1.69	
Braunschweig	**FV 4/4**	34-40	1.66	
Braunschweig	**FV12/1**	2-8	1.30	1.30
Braunschweig	**FV12/1**	2-8	1.30	
Braunschweig	**FV12/1**	2-8	1.32	
Braunschweig	**FV12/1**	2-8	1.35	
Braunschweig	**FV12/1**	2-8	1.28	
Braunschweig	**FV12/1**	2-8	1.23	
Braunschweig	**FV12/1**	10-16	1.32	1.32
Braunschweig	**FV12/1**	10-16	1.35	
Braunschweig	**FV12/1**	10-16	1.29	
Braunschweig	**FV12/1**	10-16	1.38	
Braunschweig	**FV12/1**	10-16	1.20	
Braunschweig	**FV12/1**	10-16	1.37	
Braunschweig	**FV12/1**	18-24	1.37	1.34
Braunschweig	**FV12/1**	18-24	1.34	
Braunschweig	**FV12/1**	18-24	1.30	
Braunschweig	**FV12/1**	18-24	1.40	
Braunschweig	**FV12/1**	18-24	1.41	
Braunschweig	**FV12/1**	18-24	1.22	
Braunschweig	**FV12/1**	26-32	1.34	1.38
Braunschweig	**FV12/1**	26-32	1.44	
Braunschweig	**FV12/1**	26-32	1.35	
Braunschweig	**FV12/1**	26-32	1.48	
Braunschweig	**FV12/1**	26-32	1.27	
Braunschweig	**FV12/1**	26-32	1.37	

Tab. A.8 continued

Site	Field	Depth (cm)	Dry bulk density (gcm-3)	Mean
Braunschweig	**FV12/1**	34-40	1.44	1.45
Braunschweig	**FV12/1**	34-40	1.53	
Braunschweig	**FV12/1**	34-40	1.55	
Braunschweig	**FV12/1**	34-40	1.37	
Braunschweig	**FV12/1**	34-40	1.32	
Braunschweig	**FV12/1**	34-40	1.46	
Braunschweig	**FV12/2**	2-8	1.33	1.37
Braunschweig	**FV12/2**	2-8	1.38	
Braunschweig	**FV12/2**	2-8	1.39	
Braunschweig	**FV12/2**	2-8	1.45	
Braunschweig	**FV12/2**	2-8	1.36	
Braunschweig	**FV12/2**	2-8	1.29	
Braunschweig	**FV12/2**	10-16	1.37	1.42
Braunschweig	**FV12/2**	10-16	1.45	
Braunschweig	**FV12/2**	10-16	1.43	
Braunschweig	**FV12/2**	10-16	1.32	
Braunschweig	**FV12/2**	10-16	1.48	
Braunschweig	**FV12/2**	10-16	1.49	
Braunschweig	**FV12/2**	18-24	1.43	1.42
Braunschweig	**FV12/2**	18-24	1.46	
Braunschweig	**FV12/2**	18-24	1.38	
Braunschweig	**FV12/2**	18-24	1.51	
Braunschweig	**FV12/2**	18-24	1.43	
Braunschweig	**FV12/2**	18-24	1.33	
Braunschweig	**FV12/2**	26-32	1.49	1.44
Braunschweig	**FV12/2**	26-32	1.40	
Braunschweig	**FV12/2**	26-32	1.44	
Braunschweig	**FV12/2**	26-32	1.55	
Braunschweig	**FV12/2**	26-32	1.34	
Braunschweig	**FV12/2**	26-32	1.39	
Braunschweig	**FV12/2**	34-40	1.57	1.47
Braunschweig	**FV12/2**	34-40	1.50	
Braunschweig	**FV12/2**	34-40	1.35	
Braunschweig	**FV12/2**	34-40	1.48	
Braunschweig	**FV12/2**	34-40	1.55	
Braunschweig	**FV12/2**	34-40	1.38	
Braunschweig	**FV12/3**	2-8	1.31	1.30
Braunschweig	**FV12/3**	2-8	1.40	
Braunschweig	**FV12/3**	2-8	1.27	
Braunschweig	**FV12/3**	2-8	1.41	
Braunschweig	**FV12/3**	2-8	1.22	
Braunschweig	**FV12/3**	2-8	1.19	
Braunschweig	**FV12/3**	10-16	1.44	1.36
Braunschweig	**FV12/3**	10-16	1.36	
Braunschweig	**FV12/3**	10-16	1.29	
Braunschweig	**FV12/3**	10-16	1.30	
Braunschweig	**FV12/3**	10-16	1.33	
Braunschweig	**FV12/3**	10-16	1.42	

Tab. A.8 continued

Site	Field	Depth (cm)	Dry bulk density (gcm-3)	Mean
Braunschweig	**FV12/3**	18-24	1.45	1.39
Braunschweig	**FV12/3**	18-24	1.37	
Braunschweig	**FV12/3**	18-24	1.35	
Braunschweig	**FV12/3**	18-24	1.44	
Braunschweig	**FV12/3**	18-24	1.31	
Braunschweig	**FV12/3**	18-24	1.39	
Braunschweig	**FV12/3**	26-32	1.50	1.41
Braunschweig	**FV12/3**	26-32	1.34	
Braunschweig	**FV12/3**	26-32	1.47	
Braunschweig	**FV12/3**	26-32	1.31	
Braunschweig	**FV12/3**	26-32	1.42	
Braunschweig	**FV12/3**	26-32	1.39	
Braunschweig	**FV12/3**	34-40	1.55	1.45
Braunschweig	**FV12/3**	34-40	1.38	
Braunschweig	**FV12/3**	34-40	1.50	
Braunschweig	**FV12/3**	34-40	1.47	
Braunschweig	**FV12/3**	34-40	1.37	
Braunschweig	**FV12/3**	34-40	1.41	
Braunschweig	**FV12/4**	2-8	1.22	1.29
Braunschweig	**FV12/4**	2-8	1.35	
Braunschweig	**FV12/4**	2-8	1.32	
Braunschweig	**FV12/4**	2-8	1.23	
Braunschweig	**FV12/4**	2-8	1.39	
Braunschweig	**FV12/4**	2-8	1.22	
Braunschweig	**FV12/4**	10-16	1.32	1.33
Braunschweig	**FV12/4**	10-16	1.30	
Braunschweig	**FV12/4**	10-16	1.37	
Braunschweig	**FV12/4**	10-16	1.28	
Braunschweig	**FV12/4**	10-16	1.34	
Braunschweig	**FV12/4**	10-16	1.40	
Braunschweig	**FV12/4**	18-24	1.33	1.34
Braunschweig	**FV12/4**	18-24	1.32	
Braunschweig	**FV12/4**	18-24	1.36	
Braunschweig	**FV12/4**	18-24	1.52	
Braunschweig	**FV12/4**	18-24	1.18	
Braunschweig	**FV12/4**	18-24	1.30	
Braunschweig	**FV12/4**	26-32	1.37	1.36
Braunschweig	**FV12/4**	26-32	1.39	
Braunschweig	**FV12/4**	26-32	1.31	
Braunschweig	**FV12/4**	26-32	1.46	
Braunschweig	**FV12/4**	26-32	1.27	
Braunschweig	**FV12/4**	26-32	1.33	
Braunschweig	**FV12/4**	34-40	1.46	1.43
Braunschweig	**FV12/4**	34-40	1.42	
Braunschweig	**FV12/4**	34-40	1.37	
Braunschweig	**FV12/4**	34-40	1.52	
Braunschweig	**FV12/4**	34-40	1.50	
Braunschweig	**FV12/4**	34-40	1.30	

Tab. A.8 continued

Site	Field	Depth (cm)	Dry bulk density (gcm-3)	Mean
Braunschweig	**FV/4**			
Braunschweig	**2.3**	2-8	1.47	1.41
Braunschweig	**2.3**	2-8	1.40	
Braunschweig	**2.3**	2-8	1.35	
Braunschweig				
Braunschweig	**2.3**	10-16	1.40	1.36
Braunschweig	**2.3**	10-16	1.35	
Braunschweig	**2.3**	10-16	1.34	
Braunschweig				
Braunschweig	**2.3**	18-24	1.44	1.45
Braunschweig	**2.3**	18-24	1.45	
Braunschweig	**2.3**	18-24	1.47	
Braunschweig				
Braunschweig	**1.3**	2-8	1.55	1.53
Braunschweig	**1.3**	2-8	1.57	
Braunschweig	**1.3**	2-8	1.48	
Braunschweig				
Braunschweig	**1.3**	10-16	1.47	1.46
Braunschweig	**1.3**	10-16	1.50	
Braunschweig	**1.3**	10-16	1.41	
Braunschweig				
Braunschweig	**1.3**	18-24	1.59	1.56
Braunschweig	**1.3**	18-24	1.58	
Braunschweig	**1.3**	18-24	1.52	

Tab. A. 9: Soil dry bulk density for the studied fields in Trenthorst and Mariensee

Site	Field	Depth (cm)	Dry bulk density (gcm^{-3})	Mean
Trenthorst	**FV/51**	2-8	1.42	1.39
Trenthorst	**FV/51**	2-8	1.42	
Trenthorst	**FV/51**	2-8	1.39	
Trenthorst	**FV/51**	2-8	1.35	
Trenthorst	**FV/51**	10 - 16	1.41	1.40
Trenthorst	**FV/51**	10 - 16	1.38	
Trenthorst	**FV/51**	10 - 16	1.39	
Trenthorst	**FV/51**	10 - 16	1.41	
Trenthorst	**FV/51**	18 - 24	1.45	1.46
Trenthorst	**FV/51**	18 - 24	1.47	
Trenthorst	**FV/51**	18 - 24	1.49	
Trenthorst	**FV/51**	18 - 24	1.43	
Trenthorst	**FV/51**	26 - 32	1.49	1.48
Trenthorst	**FV/51**	26 - 32	1.45	
Trenthorst	**FV/51**	26 - 32	1.48	
Trenthorst	**FV/51**	26 - 32	1.51	
Trenthorst	**FV/11**	2-8	1.33	1.34
Trenthorst	**FV/11**	2-8	1.33	
Trenthorst	**FV/11**	2-8	1.33	
Trenthorst	**FV/11**	2-8	1.36	
Trenthorst	**FV/11**	10 - 16	1.35	1.39
Trenthorst	**FV/11**	10 - 16	1.40	
Trenthorst	**FV/11**	10 - 16	1.42	
Trenthorst	**FV/11**	10 - 16	1.37	
Trenthorst	**FV/11**	18 - 24	1.42	1.45
Trenthorst	**FV/11**	18 - 24	1.43	
Trenthorst	**FV/11**	18 - 24	1.45	
Trenthorst	**FV/11**	18 - 24	1.49	
Trenthorst	**FV/11**	26 - 32	1.48	1.47
Trenthorst	**FV/11**	26 - 32	1.44	
Trenthorst	**FV/11**	26 - 32	1.45	
Trenthorst	**FV/11**	26 - 32	1.51	
Trenthorst	**FV/29**	2-8	1.30	1.29
Trenthorst	**FV/29**	2-8	1.33	
Trenthorst	**FV/29**	2-8	1.21	
Trenthorst	**FV/29**	2-8	1.33	
Trenthorst	**FV/29**	10 - 16	1.35	1.37
Trenthorst	**FV/29**	10 - 16	1.40	
Trenthorst	**FV/29**	10 - 16	1.36	
Trenthorst	**FV/29**	10 - 16	1.38	

Tab. A.9 continued

Site	Field	Depth (cm)	Dry bulk density (gcm^{-3})	Mean
Trenthorst	**FV/29**	18 - 24	1.50	1.53
Trenthorst	**FV/29**	18 - 24	1.52	
Trenthorst	**FV/29**	18 - 24	1.51	
Trenthorst	**FV/29**	18 - 24	1.59	
Trenthorst	**FV/29**	26 - 32	1.61	1.59
Trenthorst	**FV/29**	26 - 32	1.57	
Trenthorst	**FV/29**	26 - 32	1.61	
Trenthorst	**FV/29**	26 - 32	1.59	
Trenthorst	**FV/8**	2-8	1.35	1.32
Trenthorst	**FV/8**	2-8	1.34	
Trenthorst	**FV/8**	2-8	1.30	
Trenthorst	**FV/8**	2-8	1.31	
Trenthorst	**FV/8**	10 - 16	1.33	1.37
Trenthorst	**FV/8**	10 - 16	1.37	
Trenthorst	**FV/8**	10 - 16	1.39	
Trenthorst	**FV/8**	10 - 16	1.39	
Trenthorst	**FV/8**	18 - 24	1.44	1.46
Trenthorst	**FV/8**	18 - 24	1.46	
Trenthorst	**FV/8**	18 - 24	1.51	
Trenthorst	**FV/8**	18 - 24	1.42	
Trenthorst	**FV/8**	26 - 32	1.52	1.52
Trenthorst	**FV/8**	26 - 32	1.50	
Trenthorst	**FV/8**	26 - 32	1.56	
Trenthorst	**FV/8**	26 - 32	1.52	
Mariensee	**Schlag1 shallow**		1.50	
Mariensee	**Schlag1 deep**		1.40	
Mariensee	**kuhgrass**		1.42	
Mariensee	**Succession**		1.42	
Mariensee	**Moorkamp**		1.55	
Mariensee	**Fuchsberg**		1.50	

Tab. A.10: Soil penetration resistance for the studied fields

Depth (cm)	Penetration resistance (MPa) FV 36-4 (mineral)	FV 36-10 (organic)	Schlag1 (shallow tillage)	Schlag1 (deep tillage)
0	0.41	0.43	0.36	0.47
-1	0.49	0.55	0.53	0.57
-2	0.66	0.65	0.63	0.76
-3	0.72	0.72	0.71	0.86
-4	0.77	0.80	0.74	0.98
-5	0.84	0.86	0.77	1.10
-6	0.94	0.95	0.85	1.21
-7	0.99	1.05	0.88	1.28
-8	1.02	1.12	1.02	1.38
-9	1.08	1.15	1.08	1.45
-10	1.19	1.12	1.20	1.53
-11	1.15	1.16	1.25	1.67
-12	1.18	1.14	1.32	1.77
-13	1.18	1.12	1.35	1.84
-14	1.16	1.15	1.44	1.87
-15	1.11	1.20	1.59	1.93
-16	1.06	1.23	1.72	1.94
-17	1.06	1.22	1.76	1.96
-18	1.05	1.19	1.80	1.94
-19	1.05	1.13	1.83	1.93
-20	1.04	1.14	1.82	1.90
-21	1.04	1.15	1.81	1.83
-22	1.09	1.17	1.86	1.82
-23	1.17	1.21	1.75	1.82
-24	1.22	1.39	1.72	1.80
-25	1.28	1.55	1.70	1.78
-26	1.40	1.71	1.71	1.79
-27	1.54	1.90	1.68	1.76
-28	1.99	2.30	1.68	1.81
-29	2.40	2.66	1.71	1.80
-30	2.99	2.89	1.73	1.85
-31	3.51	3.08	1.73	1.85
-32	3.95	3.28	1.81	1.88
-33	4.20	3.39	1.87	1.89
-34	4.37	3.55	1.90	1.94
-35	4.57	3.66	1.90	1.97
-36	4.50	3.67	1.94	1.95
-37	4.43	3.65	1.94	1.95
-38	4.37	3.55	1.94	1.96
-39	4.15	3.33	1.93	1.99
-40	3.81	3.18	1.94	1.97
-41	3.76	2.86	1.96	1.98
-42	3.32	2.71	2.00	1.98
-43	3.23	2.26	1.97	1.98
-44	3.13	2.20	2.03	1.97
-45	2.78	2.04	2.03	1.99
-46	2.48	1.94	1.97	2.00
-47	2.40	1.94	2.00	2.02
-48	2.60	1.93	2.02	2.01

Tab. A.10 continued

Depth (cm)	FV 36-4 (mineral)	FV 36-10 (organic)	Schlag1 (shallow tillage)	Schlag1 (deep tillage)
-49	2.30	1.74	2.08	2.02
-50	2.36	1.65	2.08	2.01
-51	2.07	1.76	2.11	2.01
-52	1.99	1.82	2.11	2.01
-53	1.73	1.72	2.09	2.00
-54	2.01	1.60	2.09	1.98
-55	1.61	1.65	2.11	2.04
-56	1.66	1.71	2.20	2.10
-57	1.65	1.67	2.20	2.13
-58	1.73	1.64	2.22	2.17
-59	1.76	1.76	2.20	2.16
-60	1.69	1.49	2.18	2.21
-61	0.65	0.78	2.16	2.17
-62	0.54	0.38	2.21	2.15
-63	0.38	0.35	2.24	2.19
-64	0.39	0.36	2.24	2.18
-65	0.25	0.14	2.24	2.20
-66	0.26	0.14	2.27	2.19
-67	0.17	0.14	2.32	2.23
-68	0.19	0.14	2.32	2.26
-69	0.10	0.19	2.34	2.27
-70	0.10	0.03	2.32	2.23
-71	0.11	0.03	2.37	2.15
-72	0.11	0.03	2.39	2.14
-73	0.12	0.03	2.41	2.14
-74	0.12	0.03	2.41	2.17
-75	0.11	-0.01	2.48	2.10
-76	0.11	-0.01	2.50	1.83
-77	0.11	-0.01	2.55	1.74
-78	0.11	-0.01	2.55	1.40
-79	0.12	-0.01	2.61	1.28
-80	0.51	-0.01	2.66	1.17

Tab. A.11: Pearson Correlation between soil properties of the experimental site Braunschweig (N = 40)

	Inf	C	Bd1	Bd2	Bd3	Bd4	S1	S2	abun	bio	DHA	Sand 1	Sand 2	Silt 1	Silt 2	Clay1	Clay2
Inf																	
C	.521**																
Bd1	-.460**	-.720**															
Bd2	-.346*	-.247	.095														
Bd3	-.305	-.591**	.125	.700**													
Bd4	-.311	-.528**	.161	.606**	.831**												
S1	.177	.478**	-.188	-.291	-.470**	-.270											
S2	-.073	.597**	-.340*	.031	-.271	-.126	.796**										
abun	.832**	.679**	-.698**	-.496*	-.501*	-.484*	.561**	.324									
bio	.804**	.635**	-.667**	-.477*	-.458*	-.480*	.585**	.369	.979**								
DHA	-.144	-.361	.586**	-.152	-.305	-.446*	.284	-.182	.633**	.675**							
Sand 1	-.224	.193	-.474**	.547**	.353*	.385*	-.010	.427**	-.888**	-.848**	-.779**						
Sand 2	.461**	.227	-.272	-.183	-.130	-.155	-.128	-.314*	.173	.174	-.327	-.123					
Silt 1	.169	-.239	.558**	-.533**	-.374*	-.370*	.021	-.425**	.880**	.835**	.793**	-.983**	.124				
Silt 2	-.463**	-.295	.344*	.126	.125	.144	.108	.252	-.138	-.142	.393*	.032	-.989**	-.031			
Clay1	.105	.342*	-.687**	.287	.312*	.175	-.051	.275	.344	.354	-.608**	.567**	-.075	-.710**	.006		
Clay2	-.138	.351*	-.358*	.413**	.074	.117	.165	.492**	-.391	-.364	-.352	.609**	-.391*	-.623**	.251	.460**	

** Correlation is significant at the 0.01 level (2-tailed). * Correlation is significant at the 0.05 level (2-tailed). Inf = infiltration rate (mm h^{-1}), C = carbon stock (t ha^{-1}), Bd 1 = dry bulk density 2-8 cm (g cm^{-3}), Bd 2 = dry bulk density 10-16 cm (g cm^{-3}), Bd 3 = dry bulk density 18-24 cm (g cm^{-3}), Bd 4 = dry bulk density 26-32 cm (g cm^{-3}), S1 = aggregate stability 0-25 cm (%), S2 = aggregate stability 25-50 cm (%), abun = earthworm abundance (worms m^{-2}), bio = earthworm biomass (g m^{-2}), DHA = dehydrogenase activity (µgTPFg^{-1}.d^{-1}), Sand 1 = sand of topsoil (%), Sand 2 = sand of subsoil (%), Silt 1 = silt of topsoil (%), Silt 2 = silt of subsoil (%), Clay 1 = clay of topsoil (%), Clay 2 = clay of subsoil (%).

Tab. A.12: Pearson Correlation between soil properties of the experimental sites Trenthorst and Mariensee together (N = 28)

Variables	Infiltration	Carbon stock	Earthworm abundance	Earthworm biomass	Earthworm/ C stock	Bulk density 2-8cm	Bulk density 10-16cm	Bulk density 18-24cm	Bulk density 26-32cm	Aggregate stability 0-25cm	Sand topsoil	Silt topsoil	Clay topsoil
Infiltration													
Carbon stock	-.476(*)												
Earthworms abundance	.307	.225											
Earthworms biomass	-.109	.601(**)	.293										
Earthworm/ C stock	.665(**)	-.660(**)	.553(**)	-.168									
Bulk density 2-8cm	-.144	.099	.486(**)	-.426(*)	.189								
Bulk density 10-16cm	-.082	.051	.653(**)	-.252	.349	.933(**)							
Bulk density 18-24cm	.265	-.129	.311	.327	.281	-.168	.157						
Bulk density 26-32cm	.396(*)	-.169	.162	.404(*)	.241	-.476(*)	-.174	.937(**)					
Aggregate stability 0-25 cm	-.025	.401(*)	-.026	.499(**)	-.302	-.287	-.234	.121	.212				
Sand topsoil	.077	-.584(**)	-.499(**)	-.340	.069	-.372	-.303	.191	.280	.308			
Silt topsoil	-.201	.604(**)	.460(*)	.275	-.102	.484(**)	.367	-.390(*)	-.504(**)	-.233	-.957(**)		
Clay topsoil	.039	.533(**)	.500(**)	.367	-.043	.249	.227	.005	-.056	-.349	-.963(**)	.845(**)	

* Correlation is significant at the 0.05 level (2-tailed).

** Correlation is significant at the 0.01 level (2-tailed).